Innovation Dynamics and Nuclear Power

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Outline

1 Japanese Nuclear Power Program and Energy Demand in Asia

2 Innovation Dynamics and LWR, lessons from history of innovations

3 Advances of fossil-fired power technologies

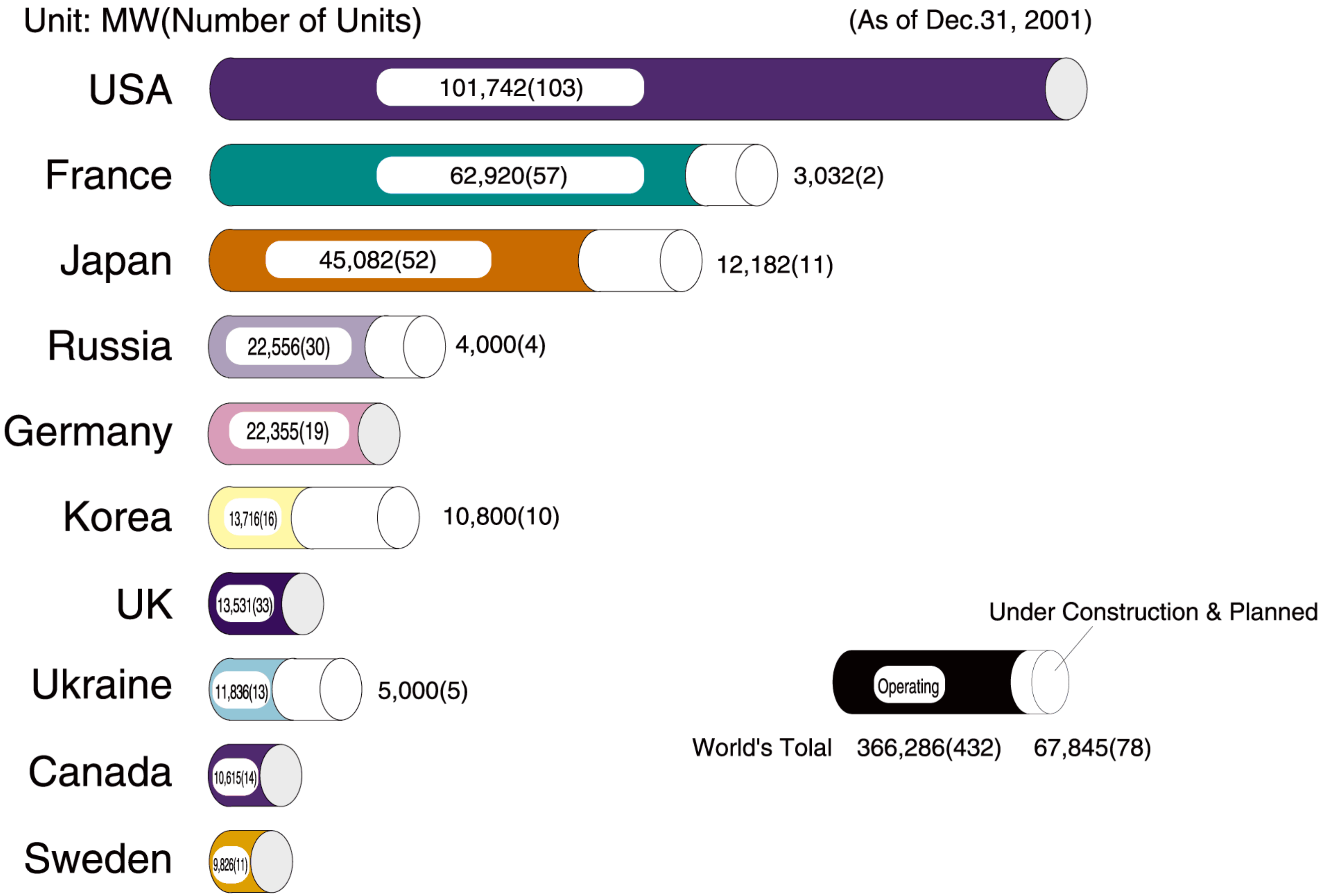
4 Evolution of boilers, once -through supercritical-pressure

reactors

5 Socio -psychological issues of nuclear energy, toward level

competition with fossil-fired power

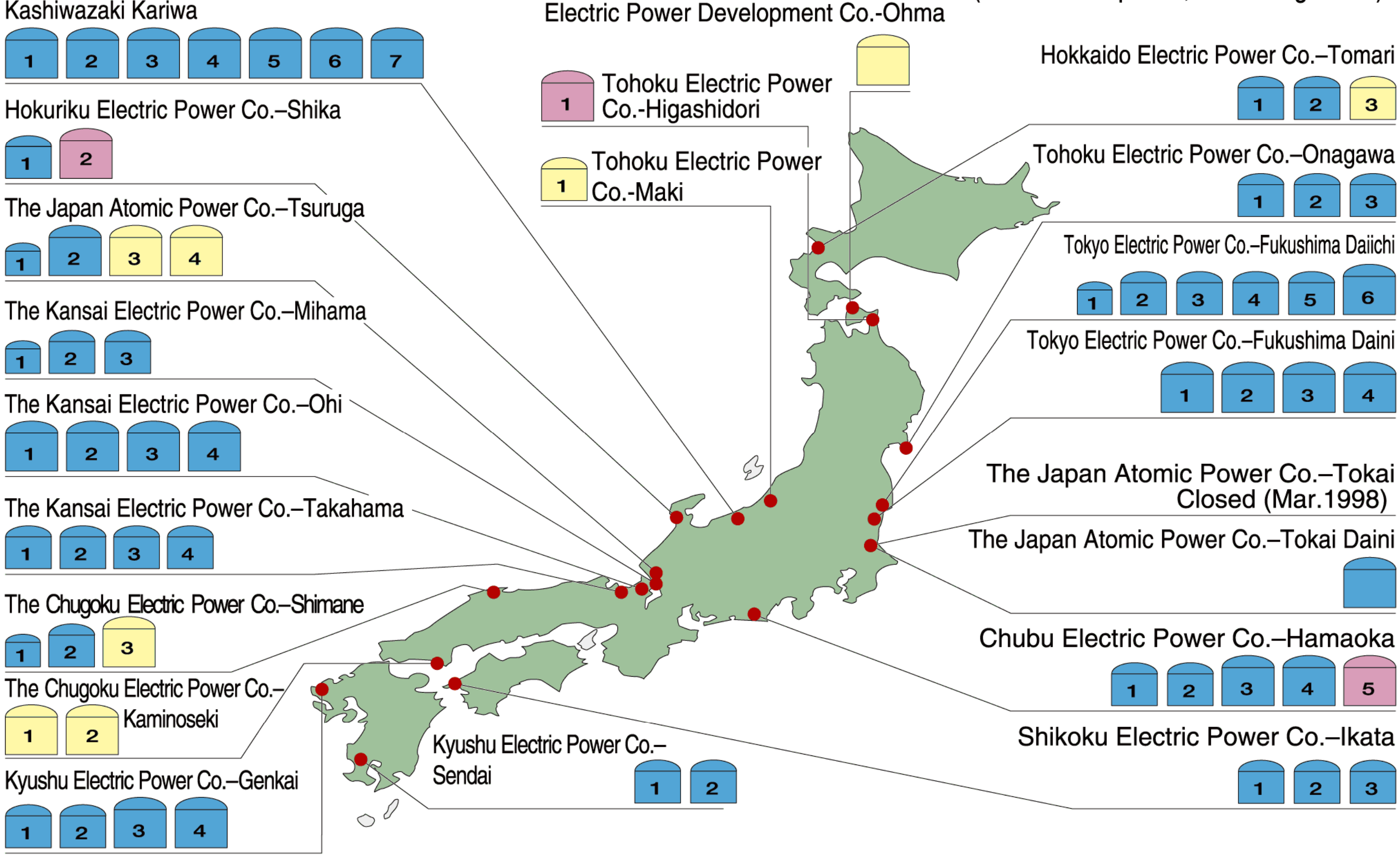
Generating Capacity of Nuclear Power Plants in Major Countries

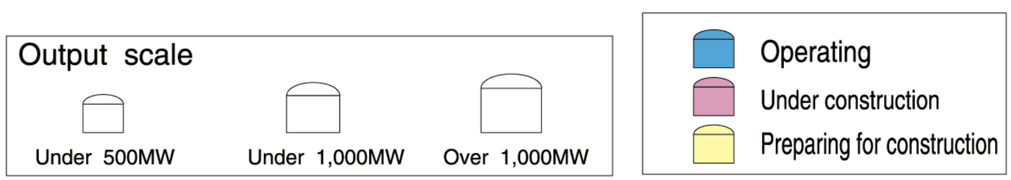


(Note) An advanced thermal reactor, "Fugen" and a prototype FBR, "Monju" are included in Japan.
(Source) Japan Atomic Industrial Forum

Nuclear Power Plants in Japan

(Commercial plants, as of Aug. 2002)



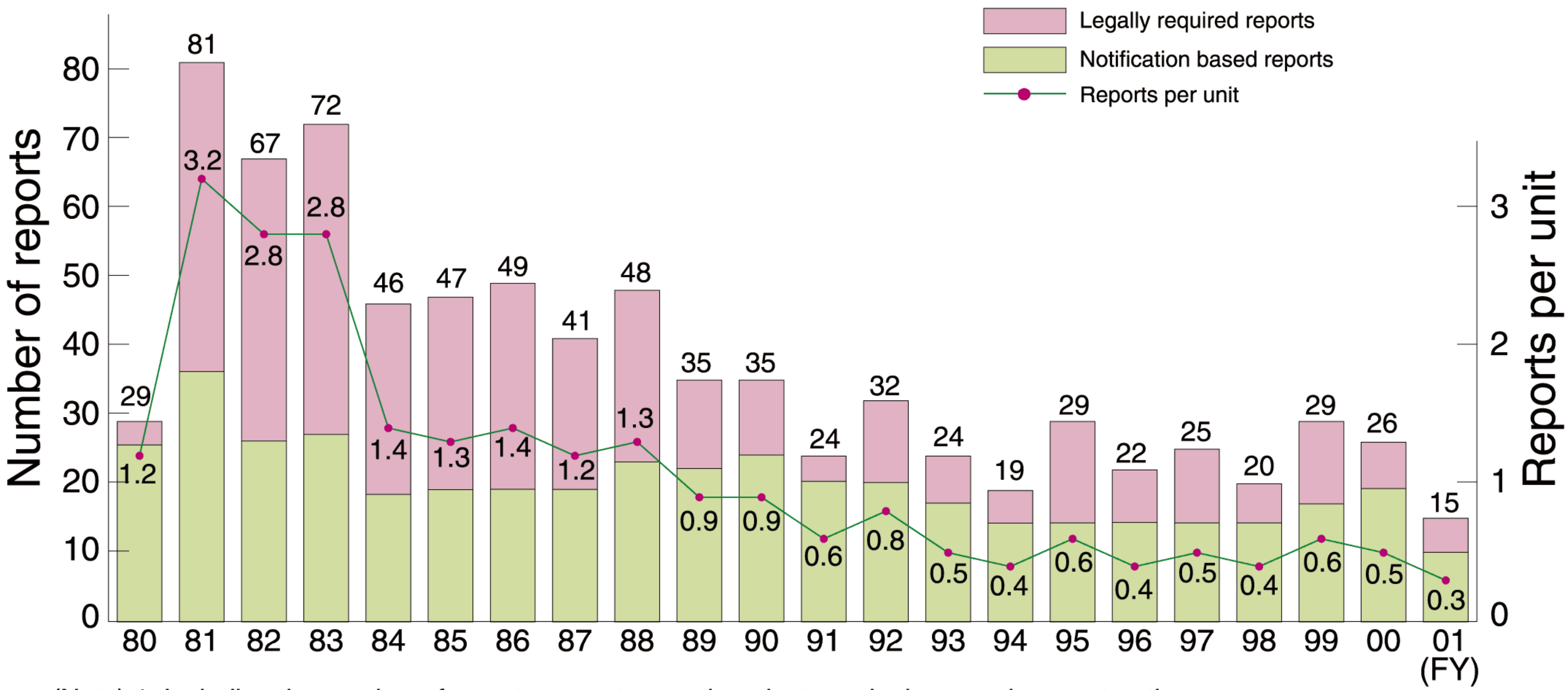


	Number of Units	Total Output (MW)
Operational	52	45,742
Under construction	3	3,838
Preparing for construction	8	10,315
Total	63	59,895

From the website of the Federation of Electric Power Companies of Japan (http://www.fepc-atomic.jp/kyouiku/kyouzai/zumen/09/index.html)

Historical Trend of Reported Incidents and Failures

(Commercial plants in Japan)

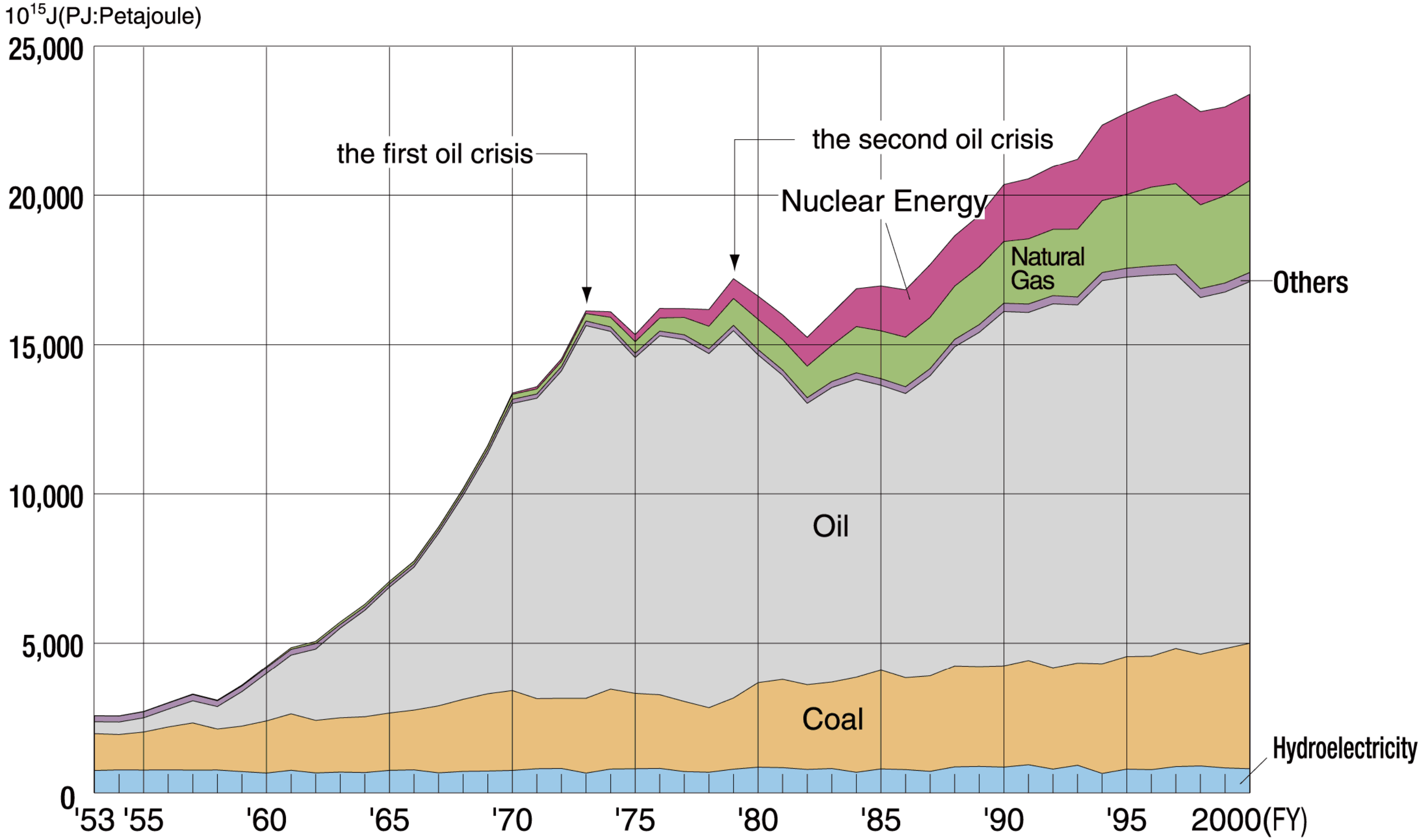


(Note) 1. Including the number of reports on test operating plants and plants under construction

2. (Reports per unit)= $\dfrac{\text{Number of reports on commercial plants}}{\text{Units of operating plants (as of the end of the FY)}}$

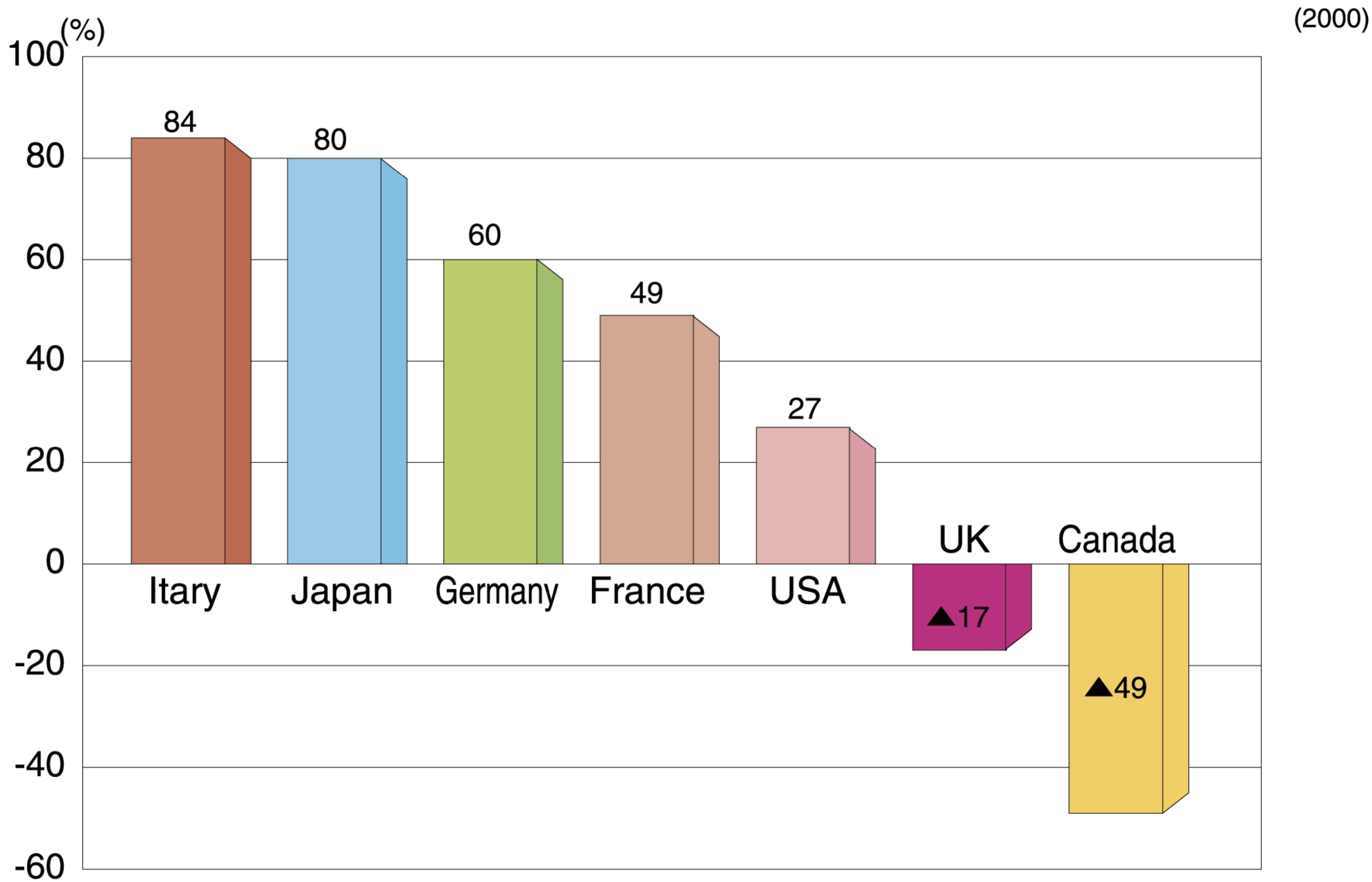
(Source) Thermal and Nuclear Power Engineering Society etc.

Historical Trend of Japan's Primary Energy Supply



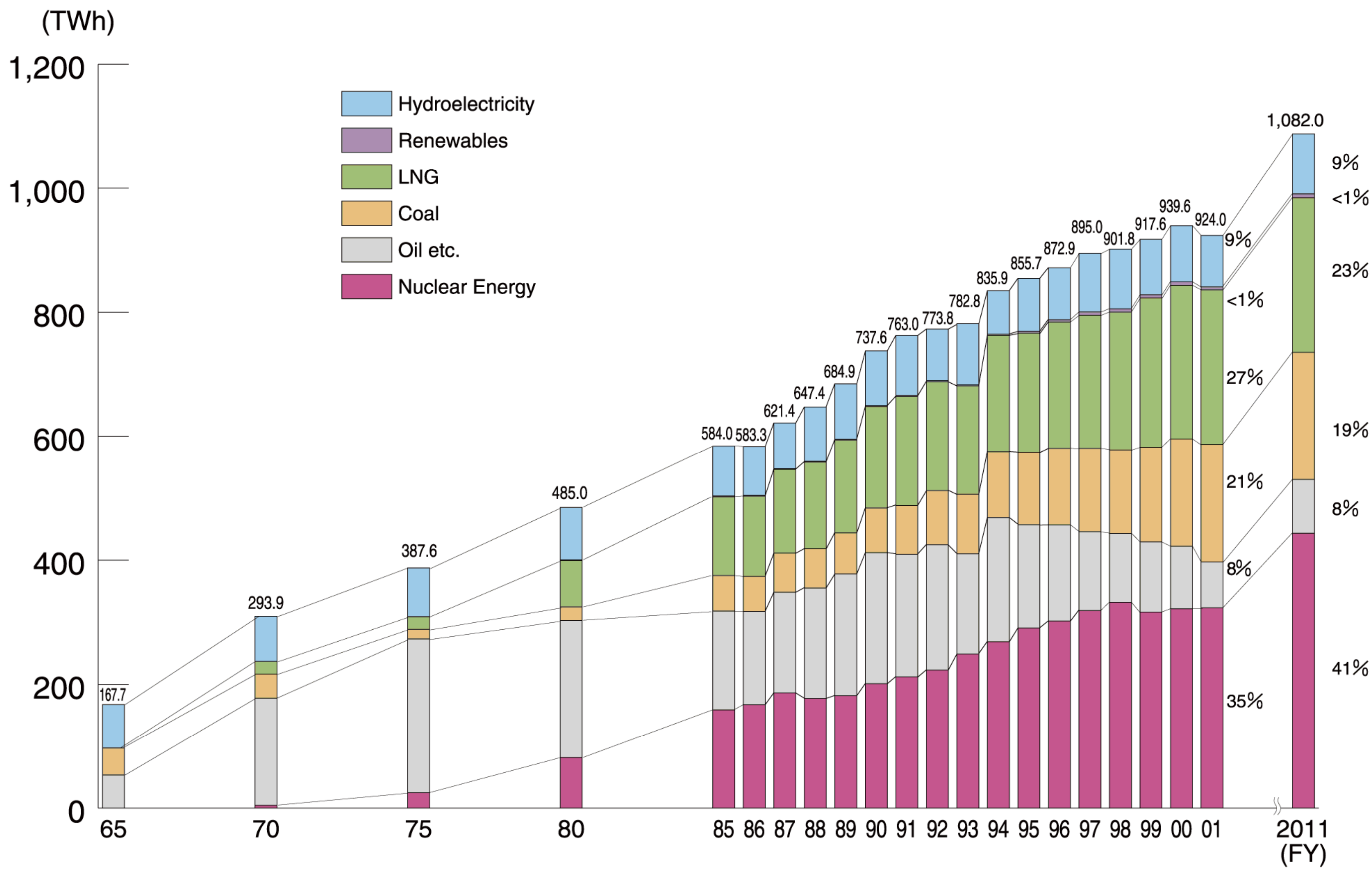
(Note) One petajoule is equivalent to approximately 25,800,000 litters of crude oil in calorie.
(Source) Agency of Natural Resources and Energy

Dependence on Foreign Resources among Major Countries



(Note) UK and Canada are net-exporting countiries
(Source) IEA, "Energy Balances of OECD Countries, 1999-2000"

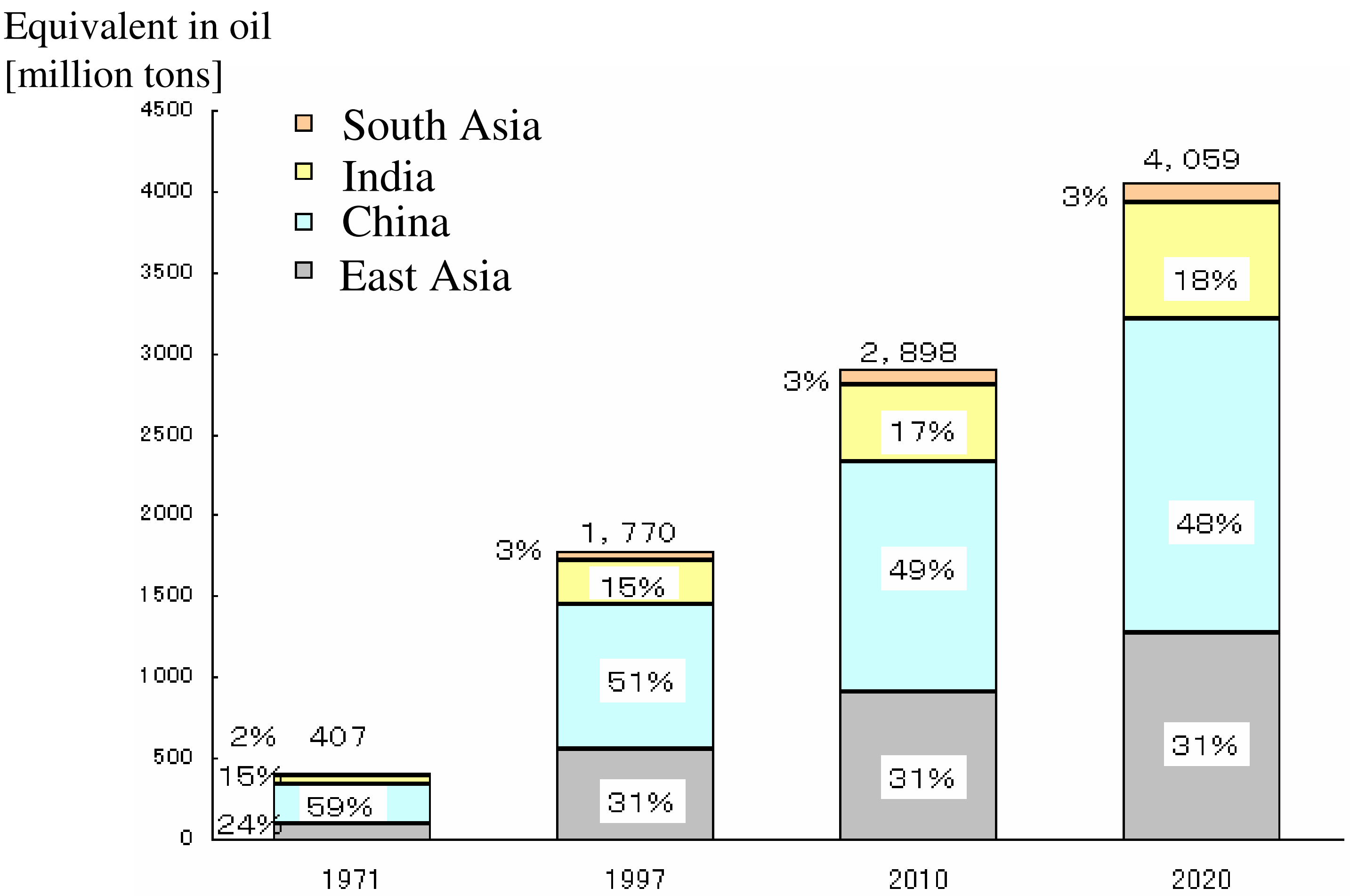
Results and Outlook of Power Generation Volume by Source



(Note) 1. Oil etc. includes LPG, other gases, and orimulsion.
2. Figures do not necessarily total to 100% due to rounded numbers.

(Source) Agency of Natural Resources and Energy, "Outline of Electric Power Development, FY2001"
The Central Electric Power Council, "Long Term Electric Power Facilities Development Plan, March 2002 " and others

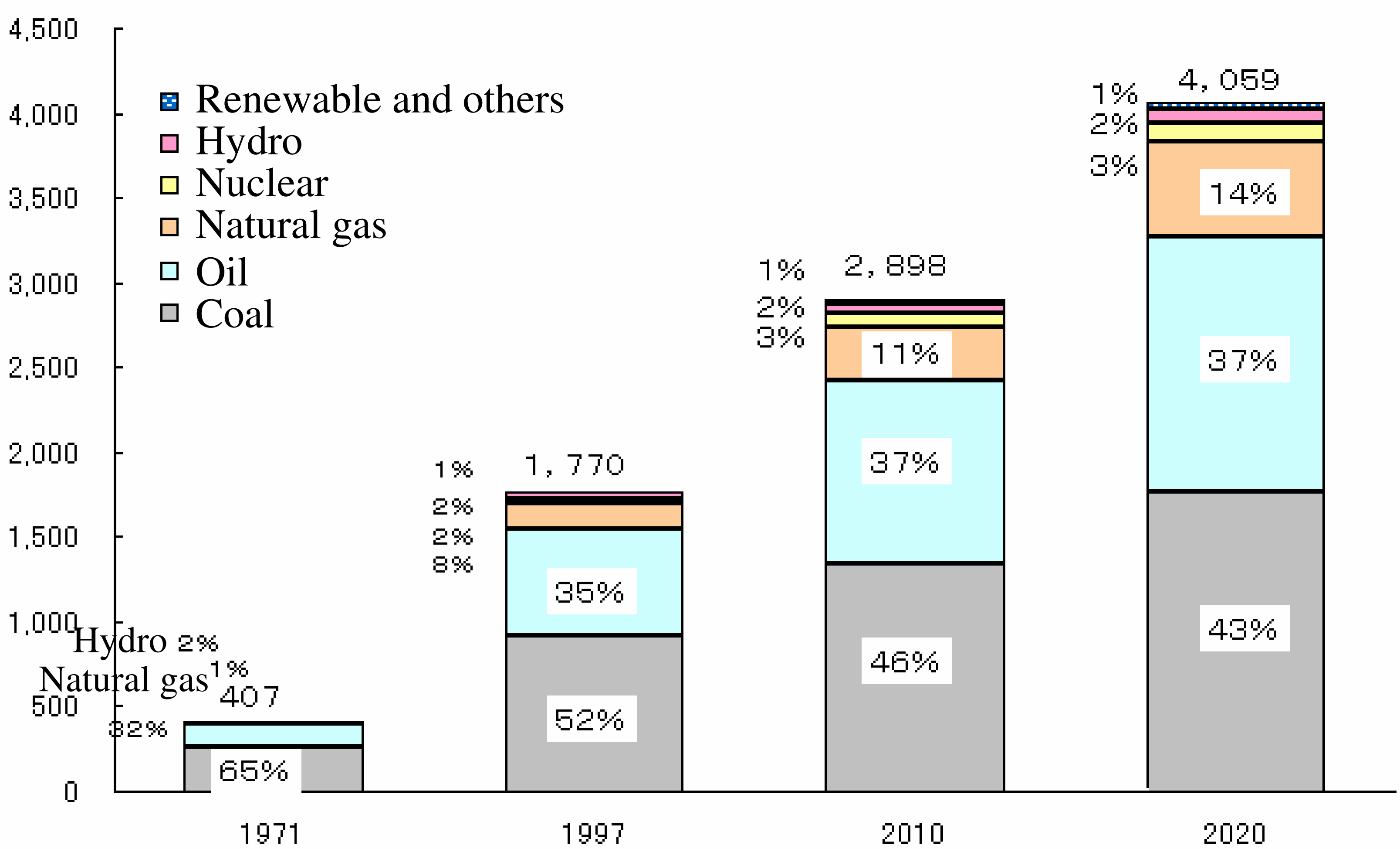
Energy Demand Trend and Outlook in Asia



(Note) East Asia: ASEAN, Korea, Taiwan…etc
South Asia: Pakistan, Bangladesh…etc

(Source) IEA / World Energy Outlook 2000

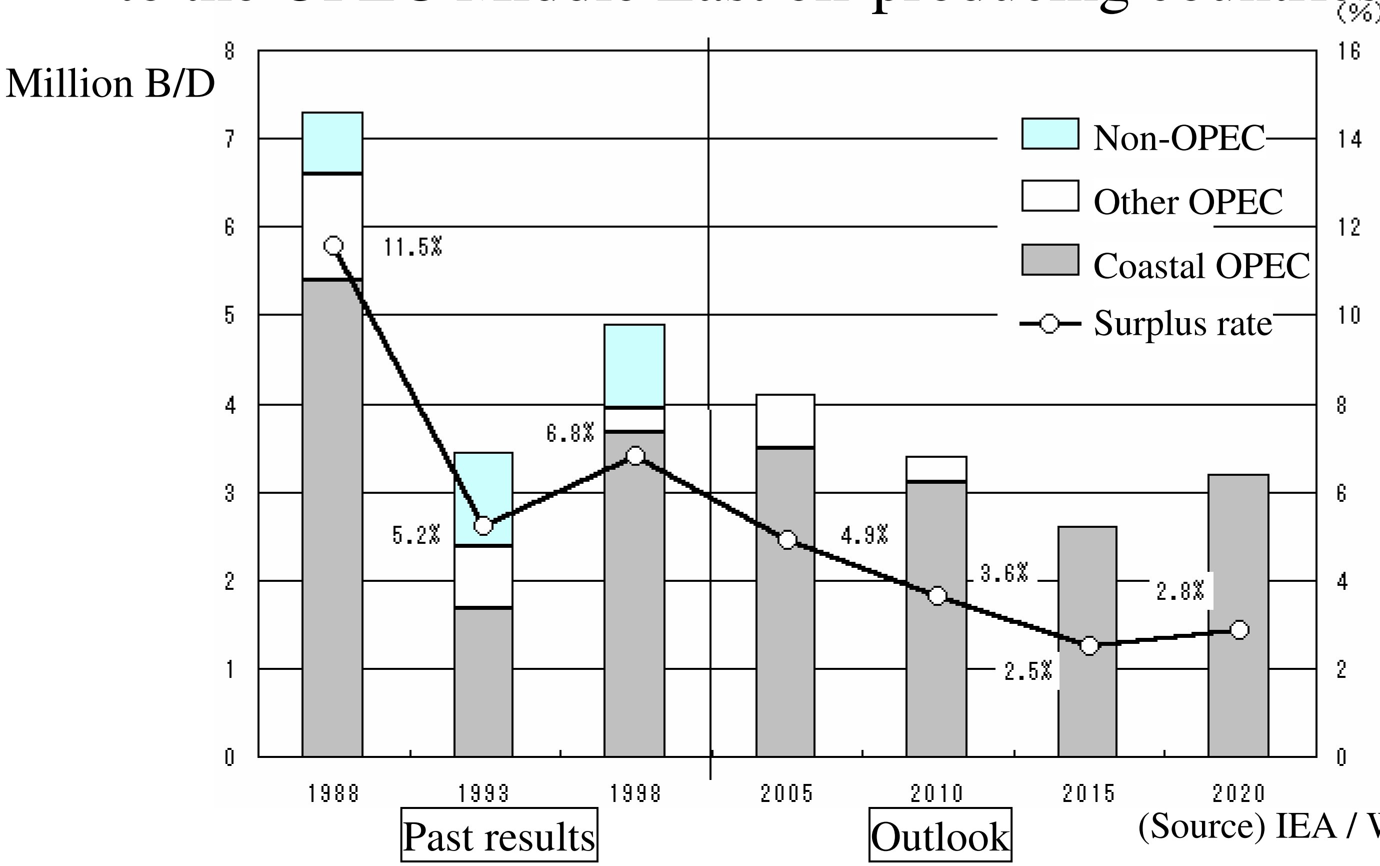
Energy Demand and Outlook by Energy Sources in Asia



(Note) Asia: China, Korea, ASEAN, India, Taiwan, Pakistan…etc (Source) IEA / World Energy Outlook 2000

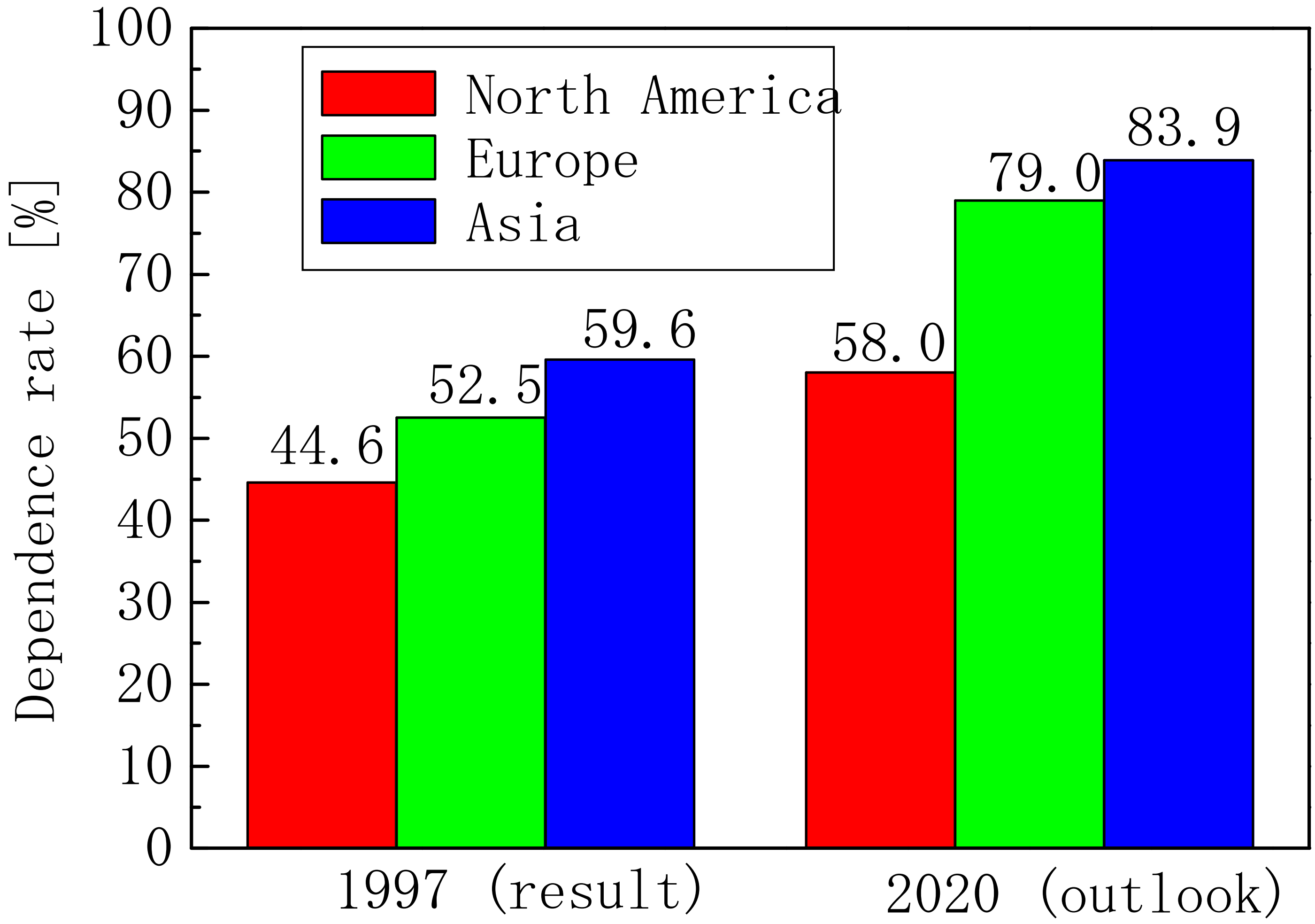
World Crude Oil Surplus Production Capacity

- Increasing trend of the Asian dependence on the Middle East
  - The world crude oil production capacity has been in the declining trend since 1990
  - The surplus production capacity is expected to be concentrated to the OPEC Middle East oil-producing countries



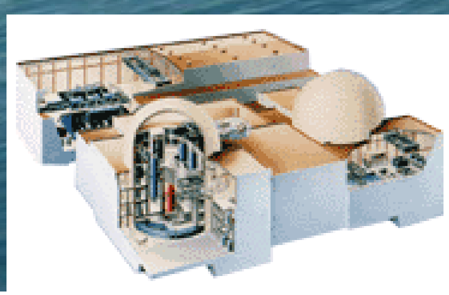
(Source) IEA / World Energy Outlook 2000

Regional Oil Import Dependencies



JAPC Tsuruga Unit 3 and 4 (APWR)

- The application for the licensing review of Tsuruga unit 3 and 4 (APWR, 1538MWe each) was made on 30th March 2004
- Construction scheduled from 2007



JAPC Tokai Unit 1(GCR) Dismantlement

- The first commercial nuclear power plant in Japan (1966-1998)
- Thermal /electric output: 585 / 166 MW
- Coolant / moderator: CO_2 / graphite

	FY2001-2005	FY2006-2010	FY2011-2017
Main process	Fuel takeout complete Safe storage	Safe storage	Dismantlement
Stage1 （prior dismantlement 1)	Preparations, turbines and other peripheral facilities removed		
Stage2 （prior dismantlement 2)		SG removed	
Stage3 (Dismantlement)			Main reactor dismantlement RB dismantle

JNFL Rokkasho Reprocessing Plant

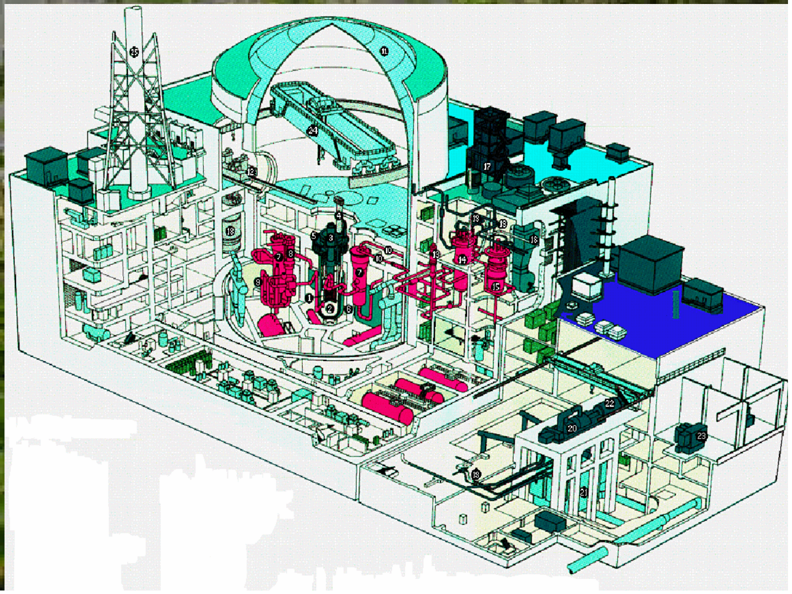
- Testing since Nov. 1999
- Site area 3,800,000m^2
- Max. reprocessing capability 800tU/yr
- Max. storage capacity 3,000tU

JNFL Rokkasho LLW Repository

- Site area 3,600,000m^2
- In service:(Unit1, 40,000m^3)1992-,
  (Unit2, 40,000m^3)1999-
- Max. future repository capacity 600,000m^3

JNC LMFBR “Monju” (Prototype Reactor)

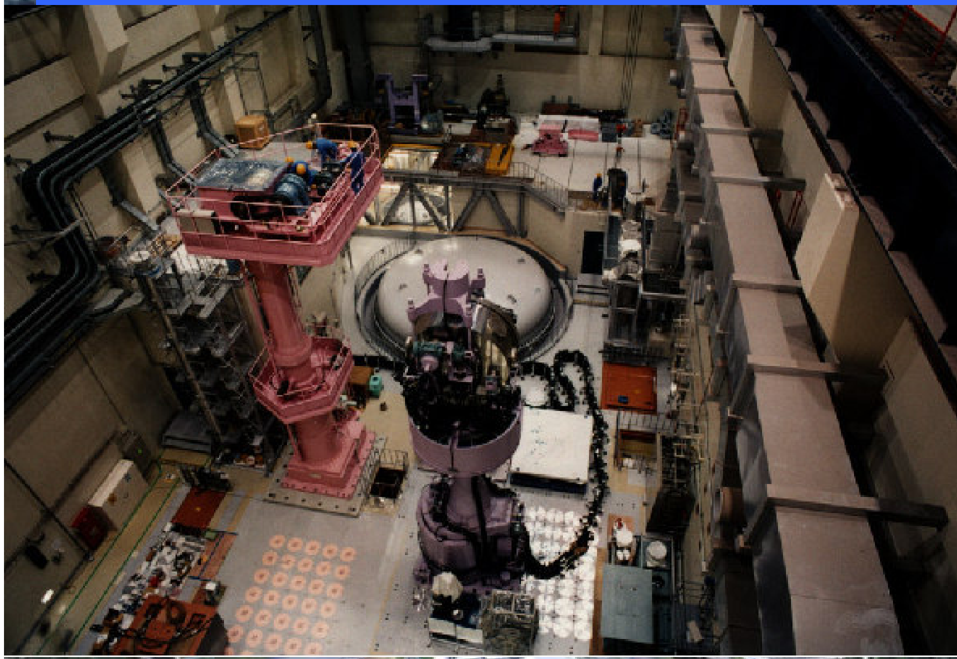
- Coolant: Liquid Na
- Thermal / electric output: 714MW / 28MW
- First criticality: April, 1994
- Stopped since 8th Dec. 1995 (Na leakage from the secondary loop)



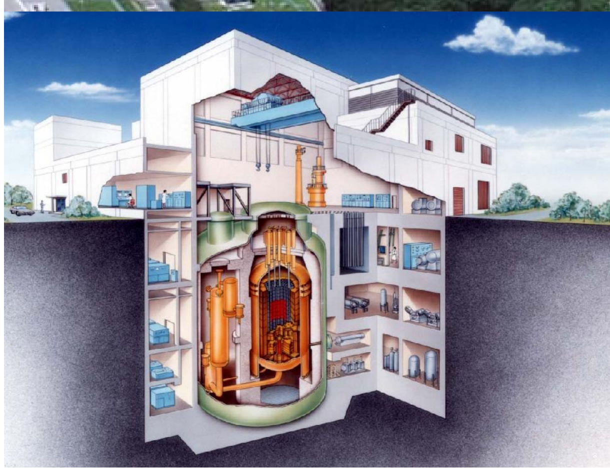
JNC LMFBR “Joyo” (Experimental Reactor)

- MK-I: “The Fast Breeder Reactor”, 75MWt (1977-1981)
- MK-II: “Irradiation Reactor”, 100MWt (1982-2003)
- MK-III: “Upgraded Irradiation Reactor”, 140MWt (2003-)

JAERI High Temperature Engineering Test Reactor (HTTR)



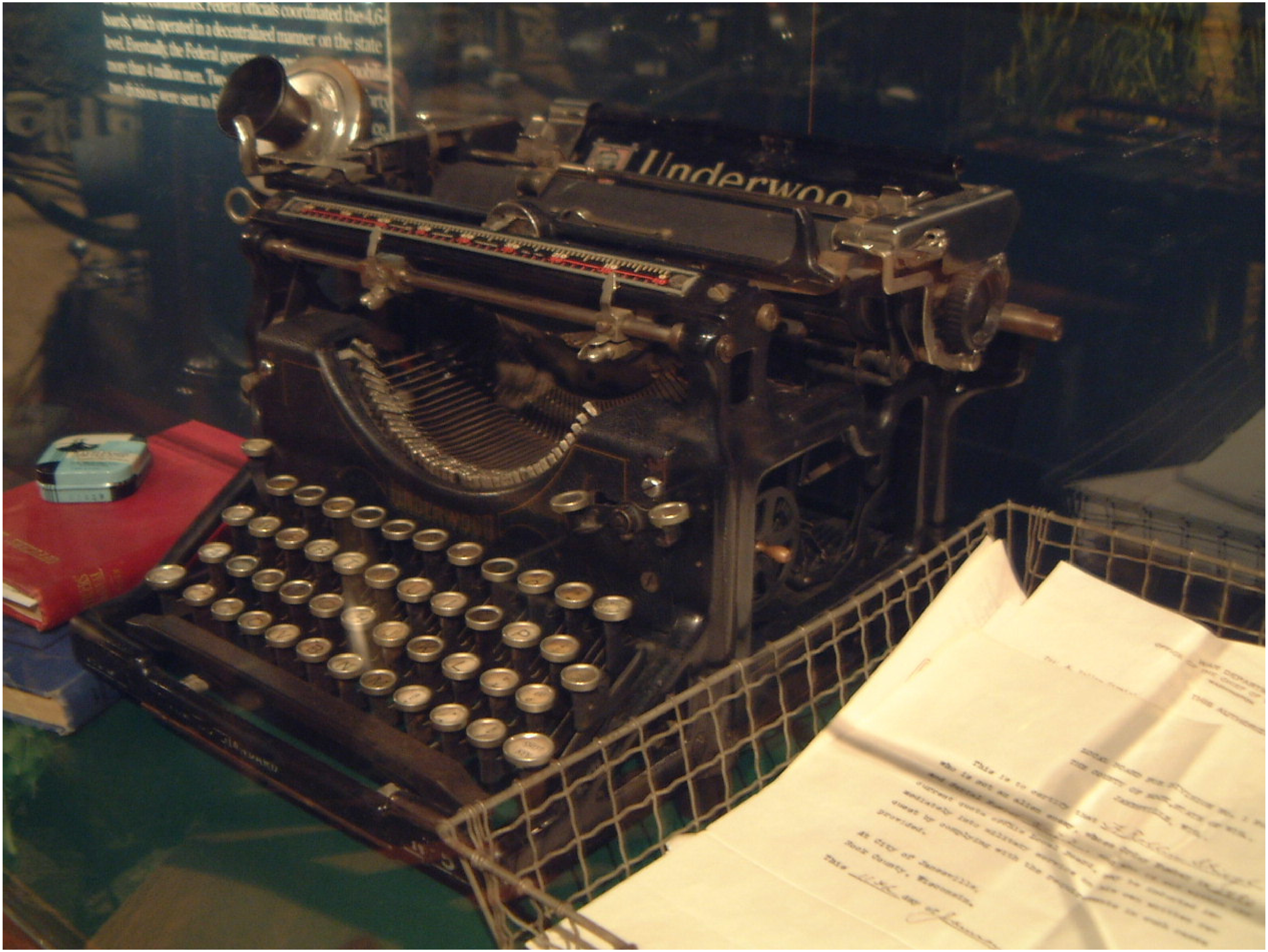
- Thermal output: 30MW
- Coolant: He gas (4MPa, 395/850-950℃)
- 21st August 2003: Succeeded hydrogen production from water with thermo-chemical I-S process.
- 19th April 2004: achieved 950℃ operation



Innovation Dynamics;

Lessons from History of Innovations

1. Typewriters
2. Lighting
3. Plate glassmaking




ROYAL

History of typewriter (machine writing)

- Manual : Remington type1 (1874), initial design

  Underwood type5 (1899), dominant design
- Powered : IBM electric typewriter
- Single purpose word processor : not successful
- Personal computer : IBM-PC

Dominant design

- The design holding largest market share
- Typewriter : arm with letters, paper role, ink ribbon, key board (QWERTY)
- Personal computer : CRT monitor, keyboard, OS, CPU, disk-drive
- Design characteristics converge to dominant design

Simplicity and technical refinement are common in dominant designs

Innovation arises from combination of existing technologies

- Manual typewriter : combination mechanical devices
- Electric typewriter : combination of manual typewriter and electric motor
- Personal computer : combination of keyboard, typing skills and electronics (CRT monitor, print board, memory chips)

Competition among companies

1. Market trial with small number of companies
2. Many company involvement with various designs
3. Survival of few companies after dominant design established

Wave of innovation in writing

hand, manual-machine, electric machine,digital technology

Changes in leadership:

Monopoly of Remington

Winning of Underwood

Electric typewriter and PC of IBM

From hardware to software(MICROSOFT)

Outsider takes leadership of innovation

Dominant company in the market tends to fail to introduce innovation

because of strategic and psychological conservatism

Innovation of lighting

- Gas lights
- Electric light bulbs (Edison)

  GE and WH hold the share

  first applied to lighting ship cabins
- Illuminating tubes

  SILVANIA holds the largest share. GE and WH developed illuminating tube, but not commercialized it first.
- Lighting diode

Production process innovation of light bulb

- Sprengel mercury pump shortened vacuum period
- Semi-automatic bulb fabrication with glass mould
- Sealing device of filament socket to bulb
- High vacuum by oxygen getter (phosphor)
- Assembling machine of glass stem and filament socket

Process innovation of plate glass making;

Innovation of material industry

1. Separate processes of mixing, melting, molding, cooling, cutting, polishing
2. Continuous process of mixing and melting
3. Continuous cooling (tunnel type cooler)
4. Continuous molding (roller molding)
5. Float process (melted glass on melted Tin)

Shortening/simplifying production processes is the innovation of material industries

Innovation dynamics

J.M.Utterback (Havard Business Shool)

・Product design innovation dominates at first

・Production process innovation becomes popular after dominant (product) design established

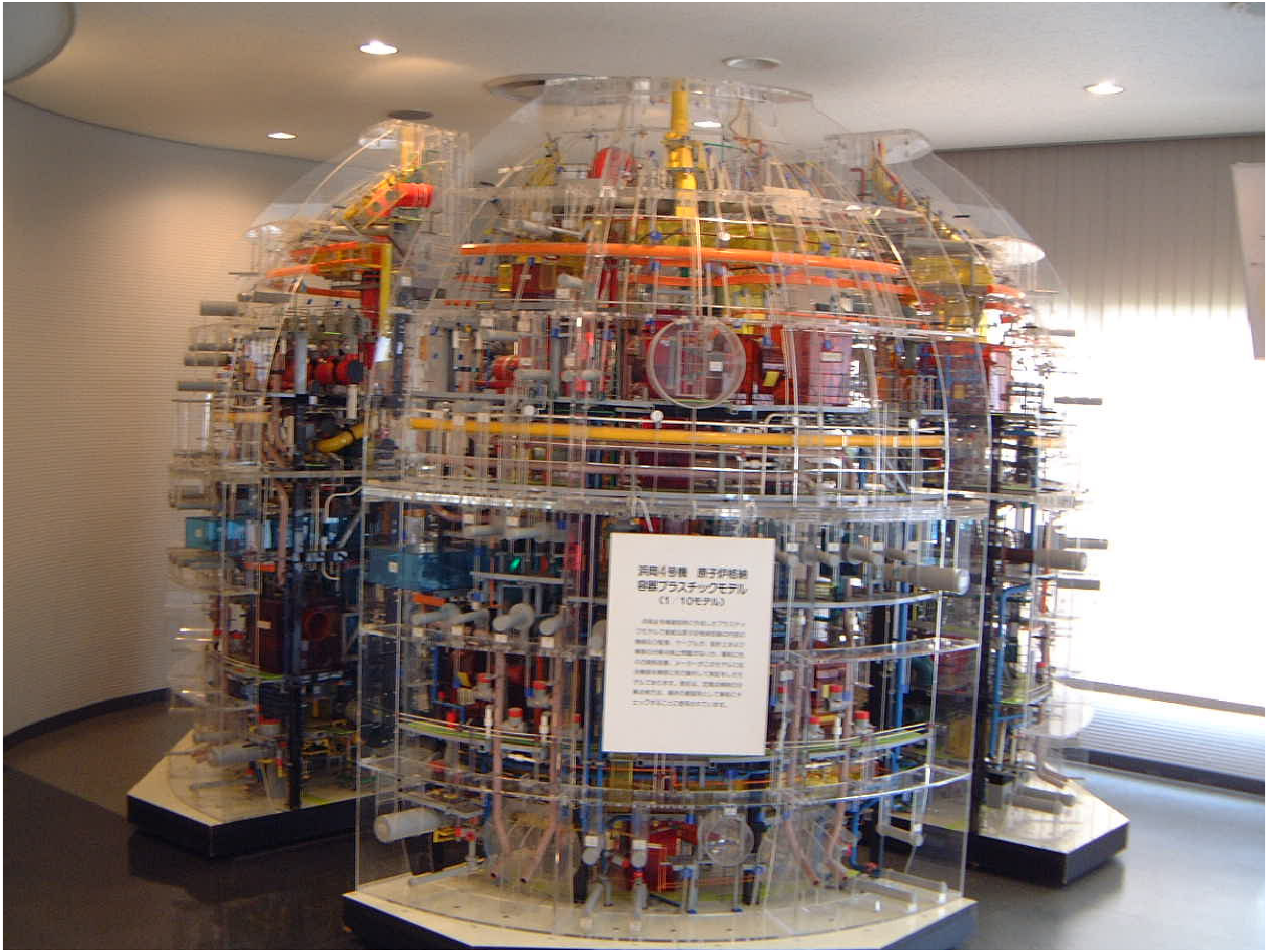
・Production process innovation dominates in material industry from the beginning

・Companies holding large market share tend to fail to introduce second product design innovation from psychological and strategic conservatism, ex. typewriters, lighting, computers

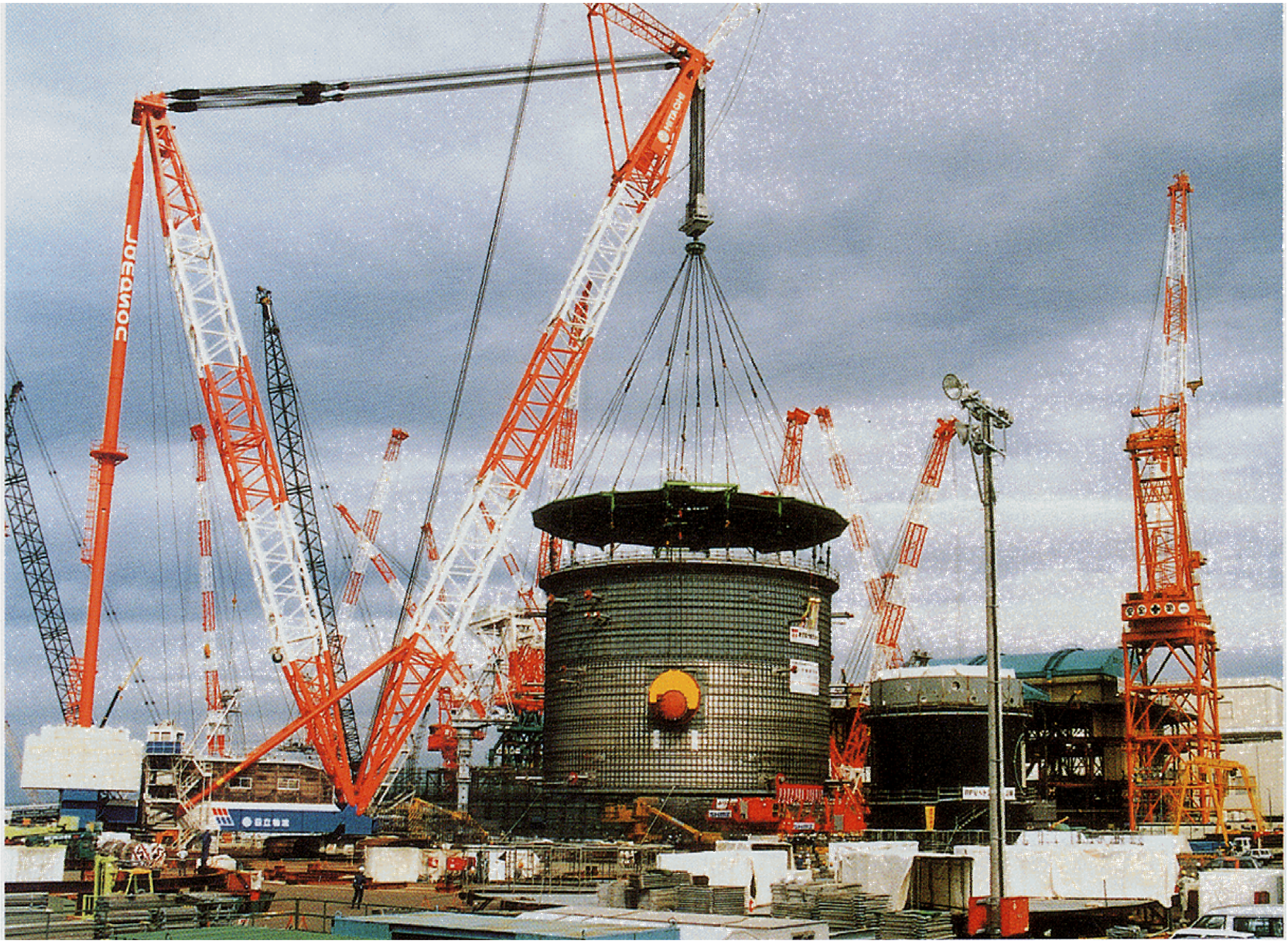
Lessons from Innovation.

Various designs are introduced to market.
Dominant design holds the largest share.
Production process innovation follows.

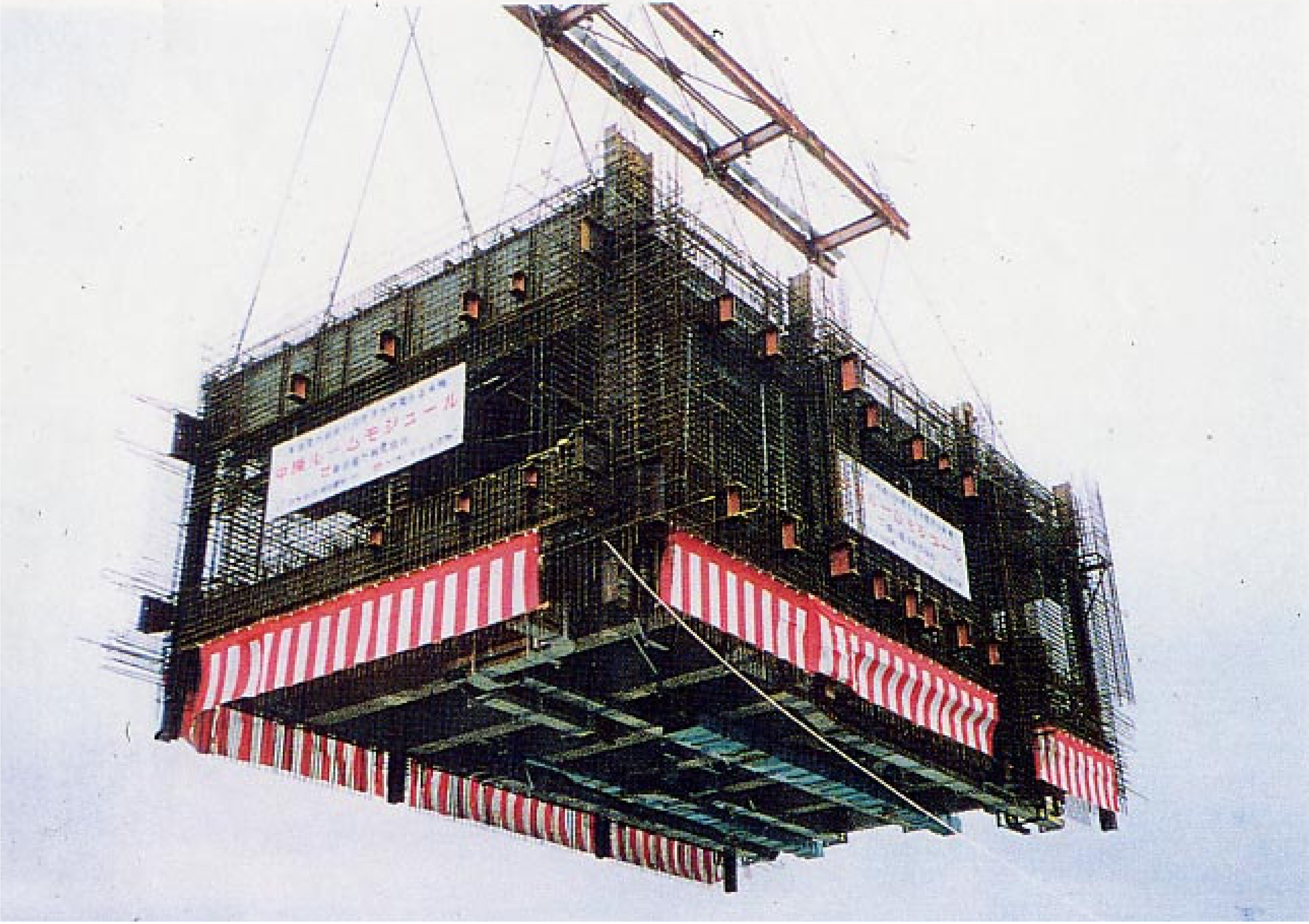
LWR is in the era of production process innovation, ex. TEPCO's Kashiwazaki Kariwa #6,7 ABWR construction


浜岡4号機　原子炉格納
容器プラスチックモデル
（1／10モデル）

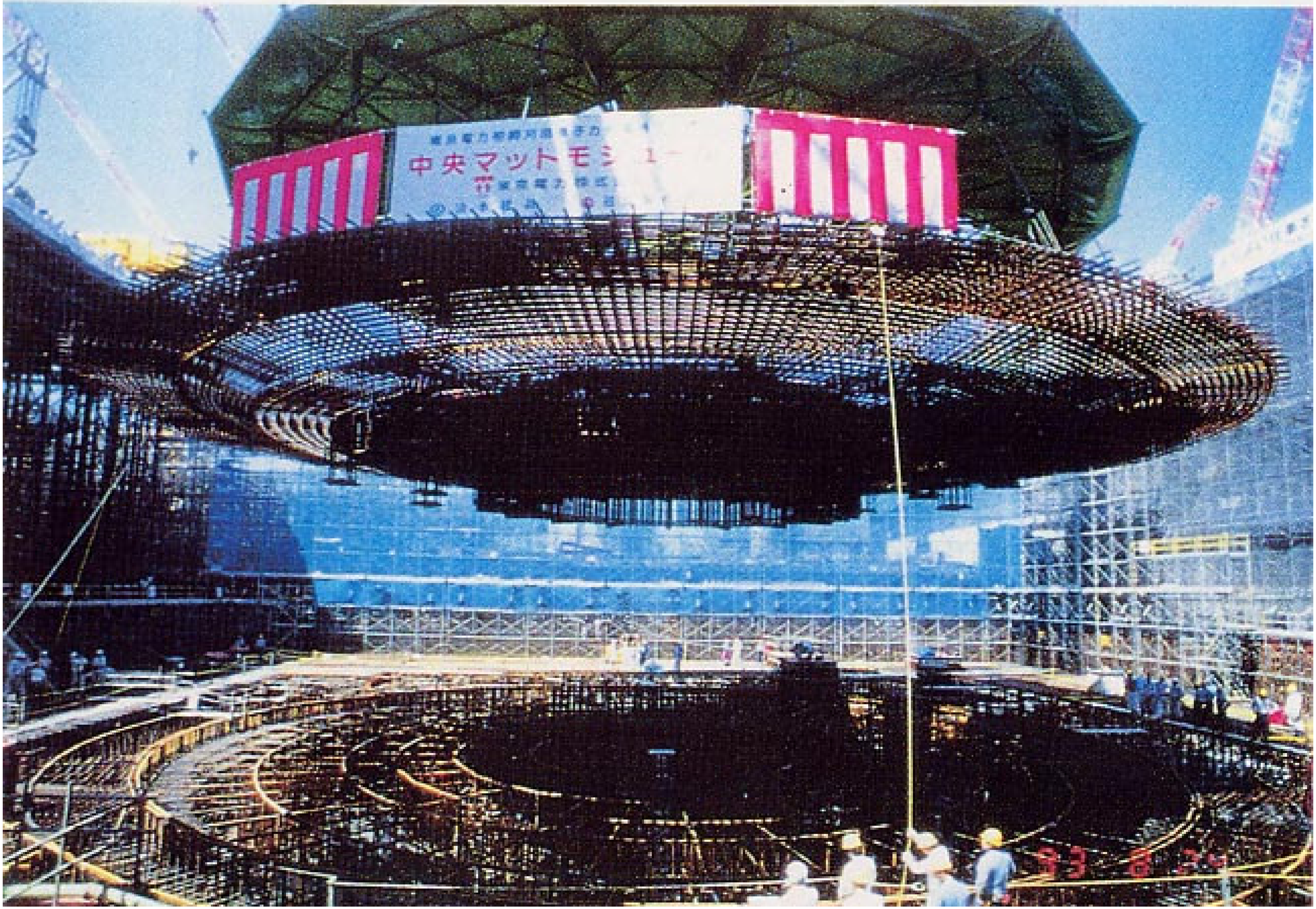
Modular construction of ABWR



Central Control Room Module



An Integrated Module of the Center Mat



Competition among thermal engines

Present

steam power: large central power station

internal combustion engine : automobile, ship etc.

jet engine: aircraft

rocket engine: rocket

past steam power applications

19^{th} century: automobile

before 1960: ships

before 1970: locomotive

Jet engine invading central power as ACC, advanced (gas turbine and steam turbine) combined cycle plants

Advances of fossil-fired power technologies

- Advances in CCGT (combined cycle gas turbine)

  high thermal efficiency (～60% LHV),

  high power output (480MWe)

  small capital investment, modular capacity addition,

  low O&M cost, short construction period

- Abundant fossil-fuel resources

  natural gas, ～84y (deep sea well drilling technology)

- Prices harved by competition of vendors in a few years
- Distributed generation ; micro turbines, diesels, fuel cells?

Nuclear energy applications

- Power generation
- Hydrogen production
- Fuel cycle

Electricity market

- Competition of centralized and distributed generation
- Best mix of energy sources from security and avoiding financial risk
- Nuclear power is the realistic option in protecting global warming and energy security.
- Capital expenditure of new plants is very large for deregulated utilities.

Net Present Value (NPV) and Internal Rate of Return (IRR) of Nuclear Power Plants (Japanese case)

NPV; 100MJen (IRR; %)	Operating 600MWe plant	Operating 1100MWe plant	New 1350MWe Plant
Present (85%capacity factor)	-366 (-)	1085 (10.2%)	621 (4.2%)
(1) Power up rate, 5%	-245 (-)	1303 (11.4%)	809 (4.5%)
(2)18 months cycle &40days inspection period	-168 (-)	1476 (12.3%)	1224 (5.3%)
(1)+(2)	-63 (0.9%)	1715 (13.6%)	1440 (5.6%)
(1)+(2)+ same O&M cost as US plants	278 (10.2%)	1844 (14.3%)	1440 (5.6%)

Source: T.Itoh, Energy Review, Sep 2003 pp.6-10 (in Japanese)

Challenge of nuclear energy in de-regulation

- New construction of present product:challenge of utilities and investors

    earnings dilution

    investment risk, stock price decrease

- Innovative reactor R&D and deployment ; challenge of vendors

    Vendors cannot invest long-term R&D by themselves.

    R&D support with government

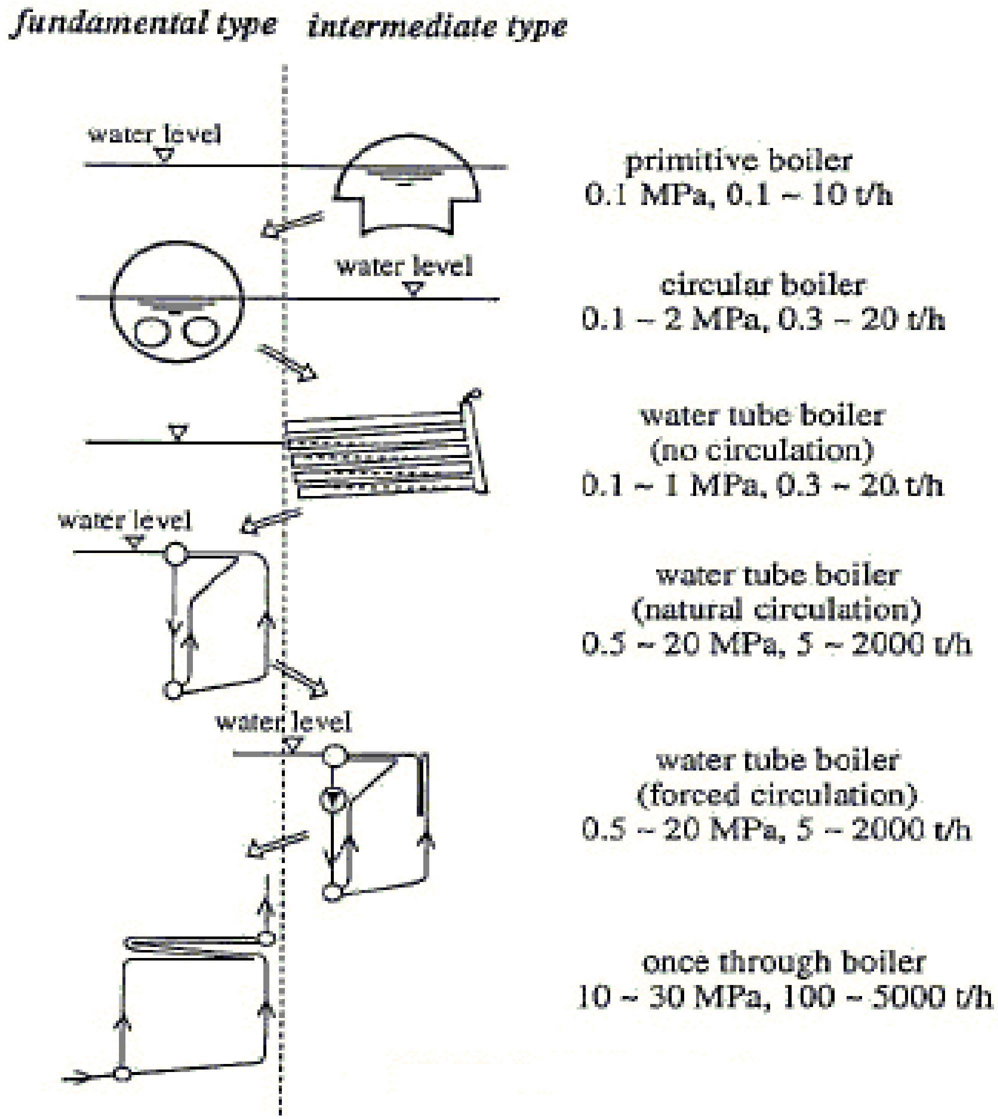
    prototype demonstration by national labs.

    need a good business model including R&D for commercialization

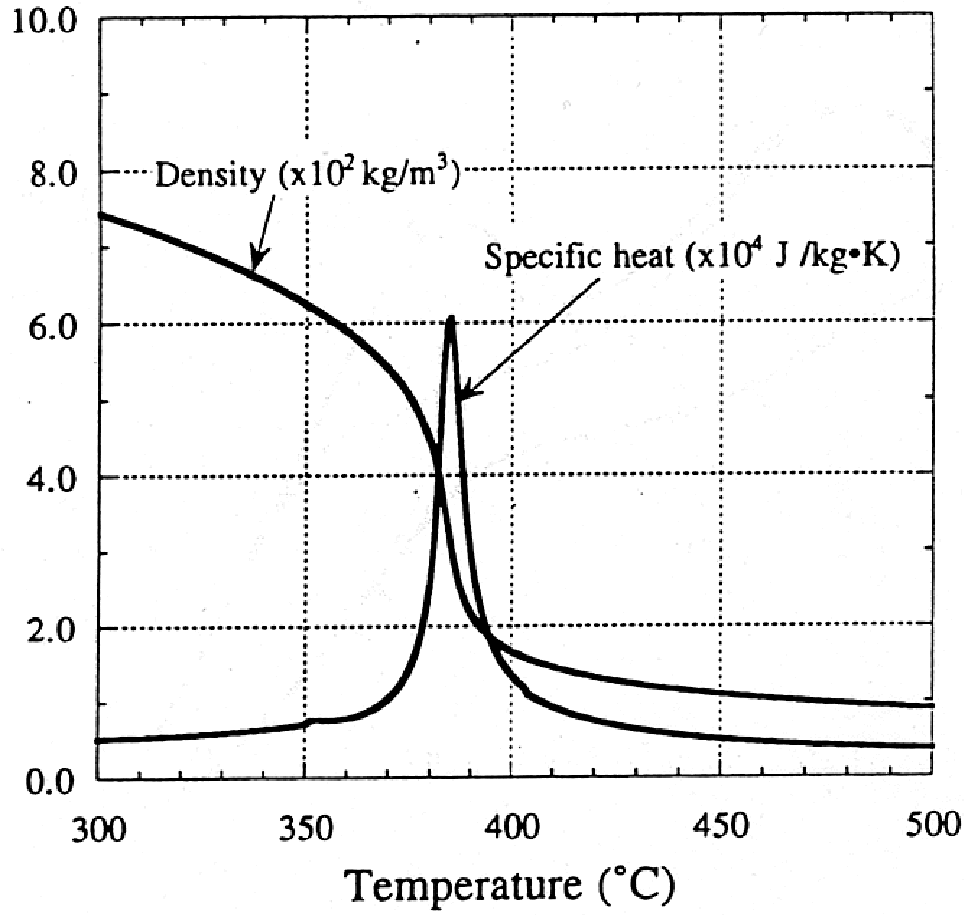
Energy market

- High quality hydro carbon production from non-conventional oil resources is commercialized.
- Other possibility will be biomass (major in global warming scenario).
- Hydrogen production from water is a good goal from environment and security.
- Commercialization will be driven by market including pollution and global warming cost.
- Infrastructure of distribution is important.

SCWR, Supercritical-pressure Light Water Cooled Reactor

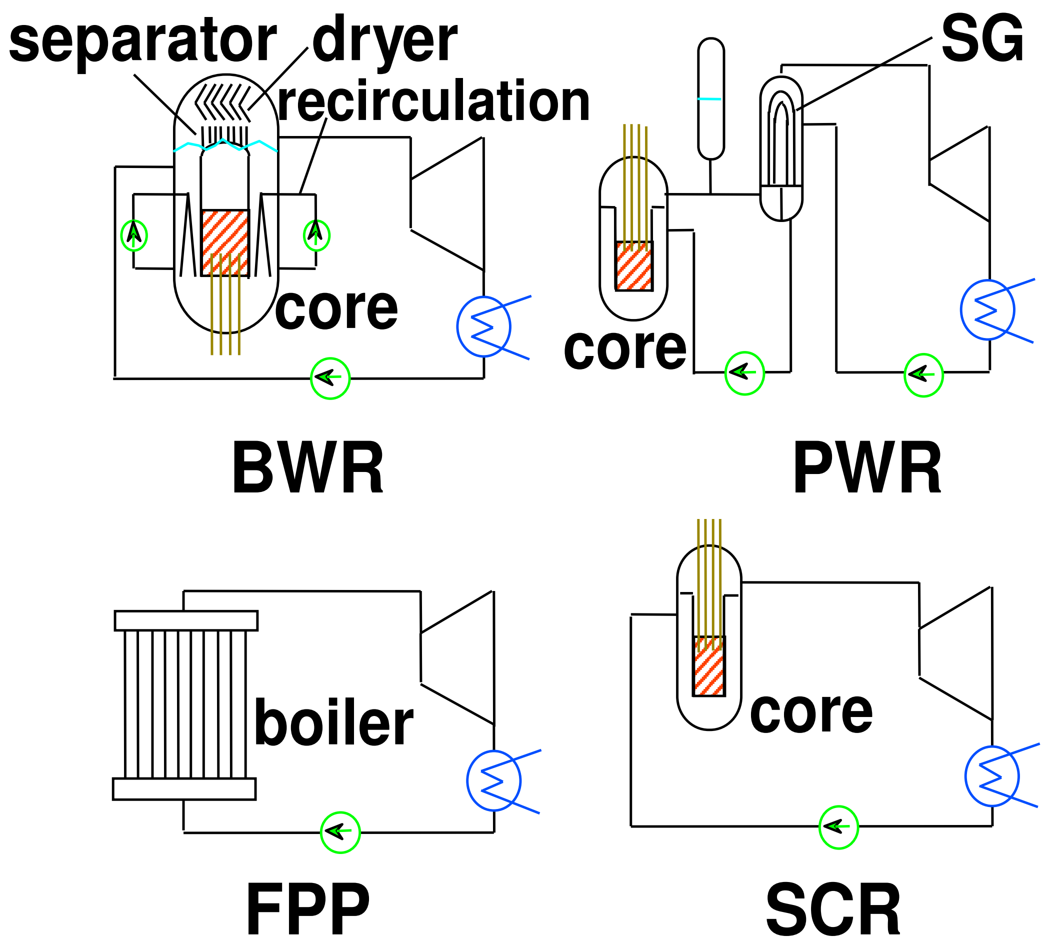


Evolution of boilers



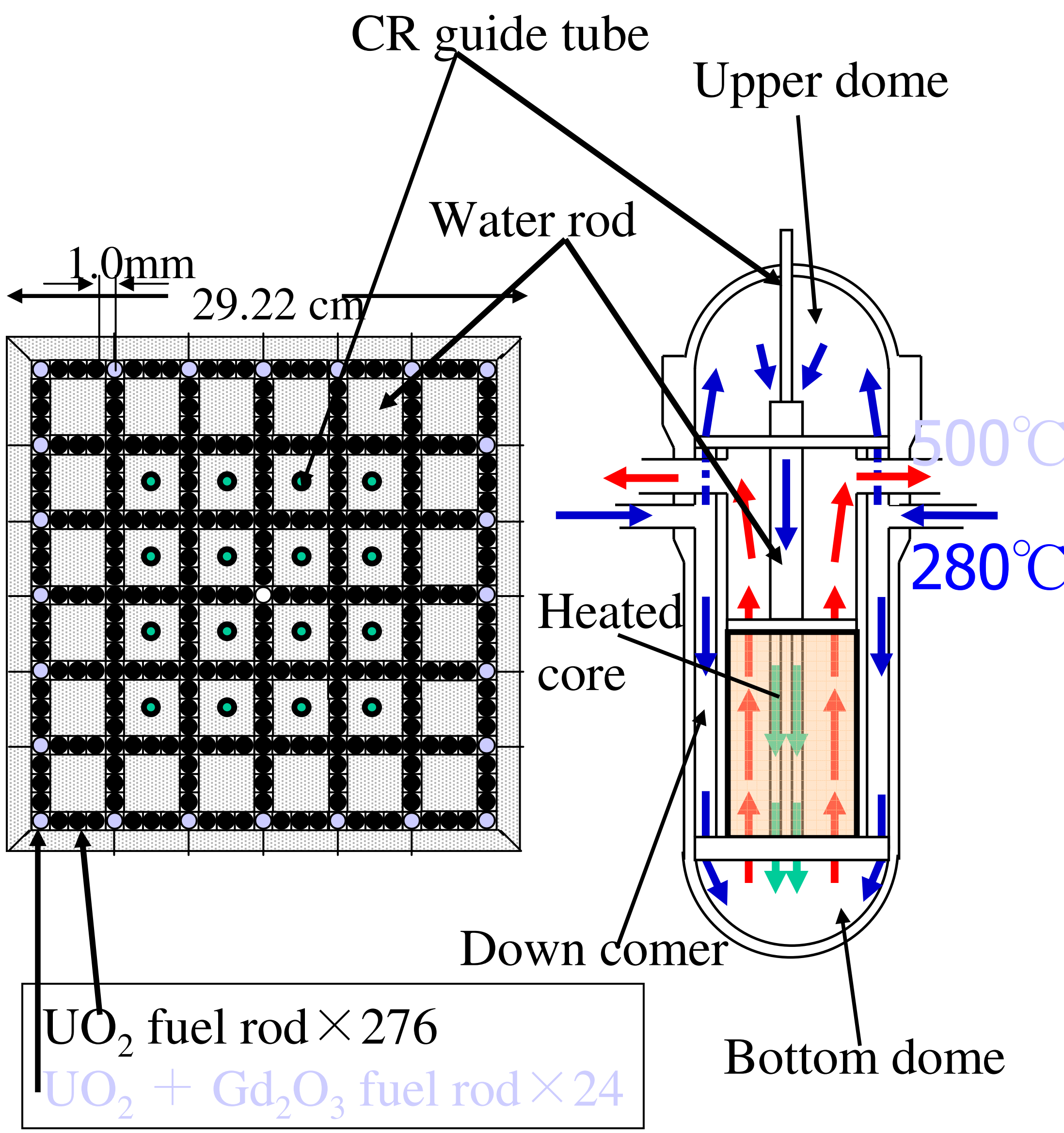
Density and specific heat

of supercritical water (25 MPa)



Comparison of plant systems

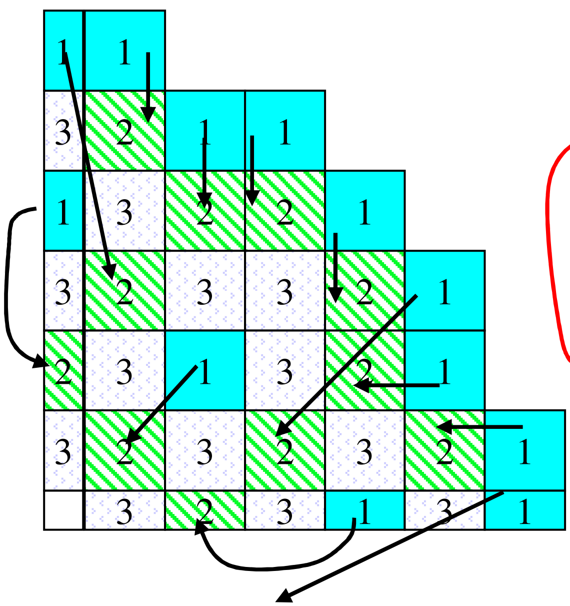
FA and coolant flow scheme



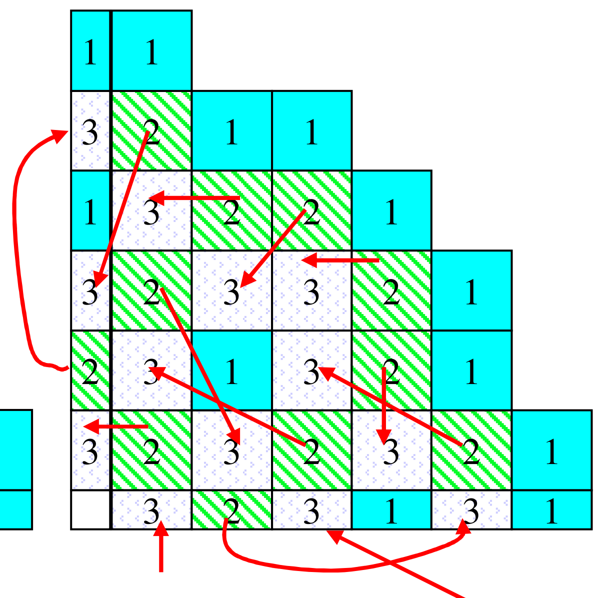
- Uniform sub-channel flow and neutron moderation
- RPV is cooled by inlet coolant (280℃)
- Avoid thermal fatigue of CR guide tube
- High average outlet temperature (500℃)
- Reduce axial change in average density

Core design (equilibrium core fuel replacement)

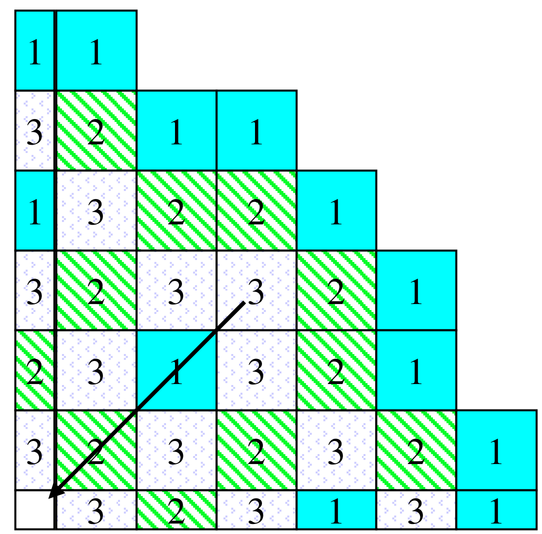
- 120 FAs (1st to 3rd cycle) + 1FA(4 th cycle)
- Similar to the fuel load pattern of PWR



1st ⇒ 2nd cycle



2nd ⇒ 3rd cycle



3rd ⇒ 4th cycle

Core design features

High coolant outlet temperature～500 (SCLWR-H)

downward flow in water rods, minimize by pass flow

Low outlet coolant density, 1/4 of BWR, 1/7 of PWR

many water rods in fuel subassembly

Low core coolant flow rate, 1/8 of BWR, 1/12 of PWR

enhance coolant velocity in narrow fuel channel

No steam water separation

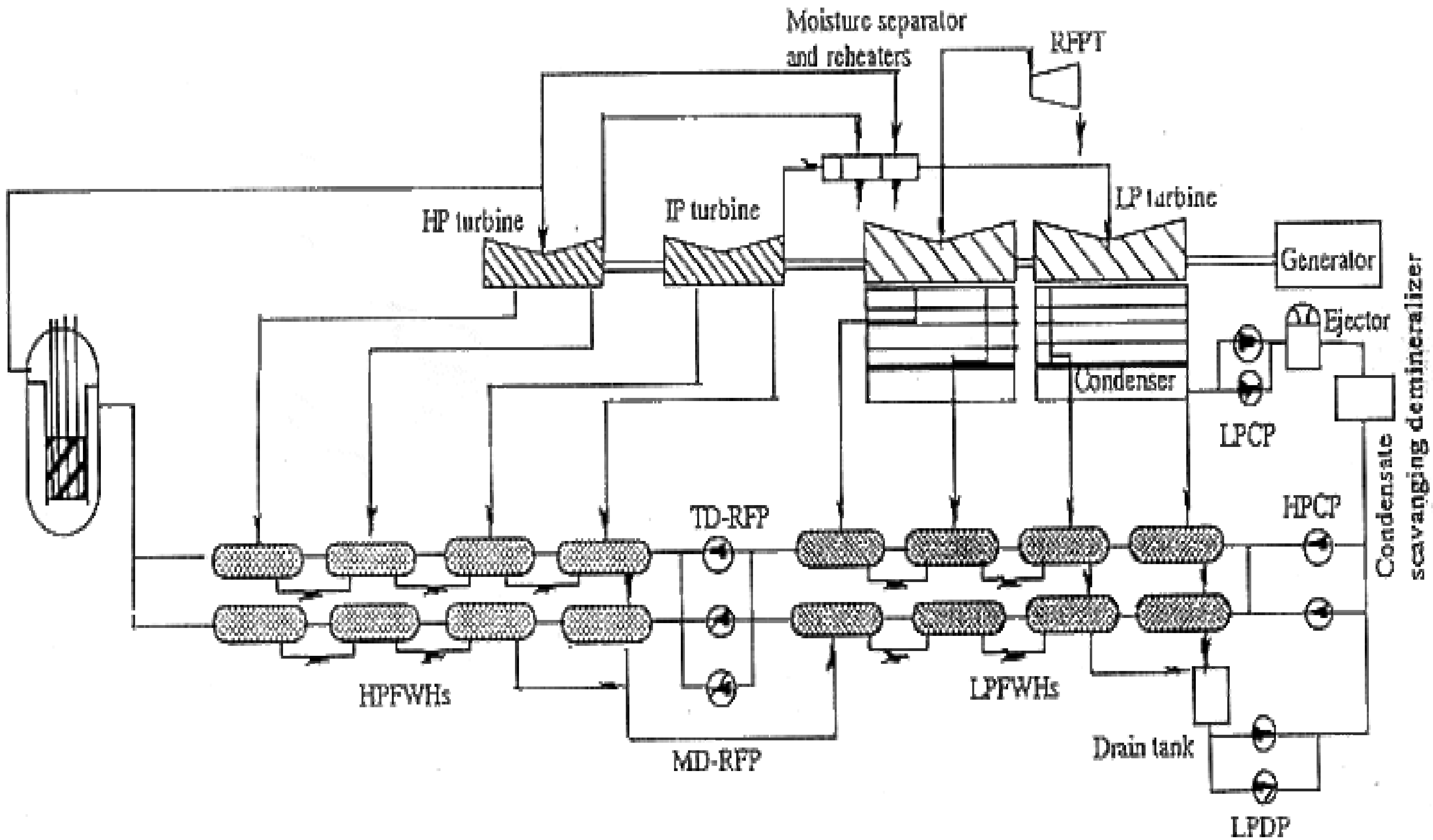
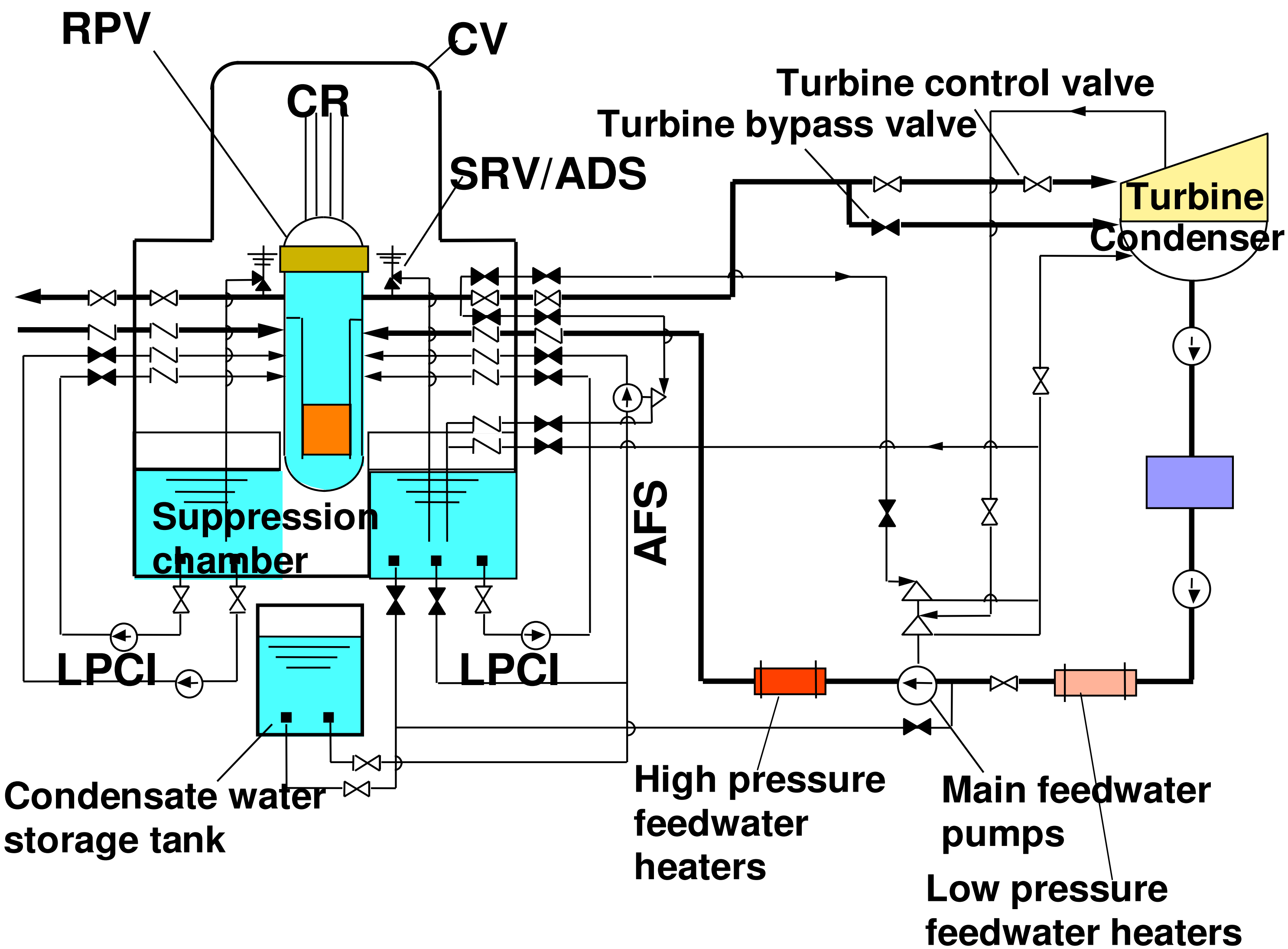


Fig.6 Flow diagram of SCLWR-H

Comparison of plant characteristics

	ABWR	PWR	supercritical fossil-fired power plant	supercritical water cooled reactor SCLWR-H
coolant system	direct-cycle with recirculation	indirect-cycle	once-through direct-cycle	once-through direct-cycle
electric power, MW	1350	1150	1000	1000*
thermal efficiency, %	34.5	34.4	41.8	44.0
primary pressure, MPa	7.2	15.5	24.1	25
inlet/outlet temperature, C	269/286	289/325	289/538	280/508
coolant flow rate, t/s	14.4	16.7	0.821	1.16
coolant flow rate/power, kg/s/MWe	10.6	14.5	0.821	1.16

*The power rating depends on market. 1700, 1000, 700MWe plants are under study.



SCLWR-H plant system

Capacity and configuration of safety system

Capacity:

AFS	**TD 3 units: 50kg/s/unit (4%) at 25MPa**
LPCI/RHR	**MD 3 units: 300kg/s/unit (25%) at 1MPa**
ADS/SRV	**8 units: 240kg/s/unit (20%) at 25MPa**

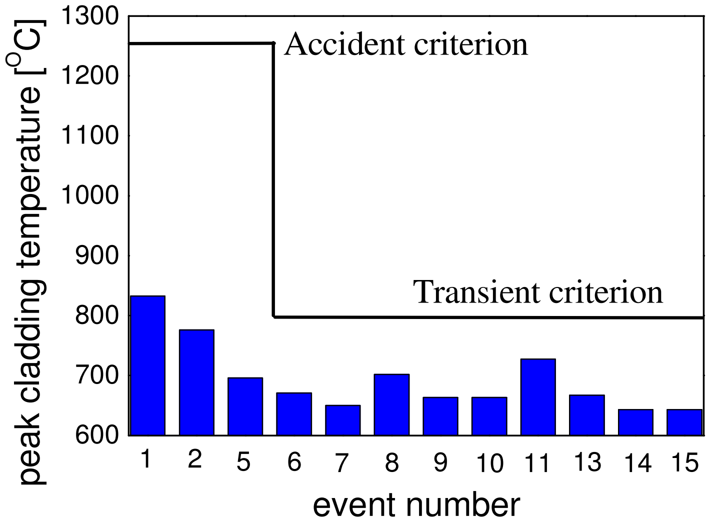
Configuration:

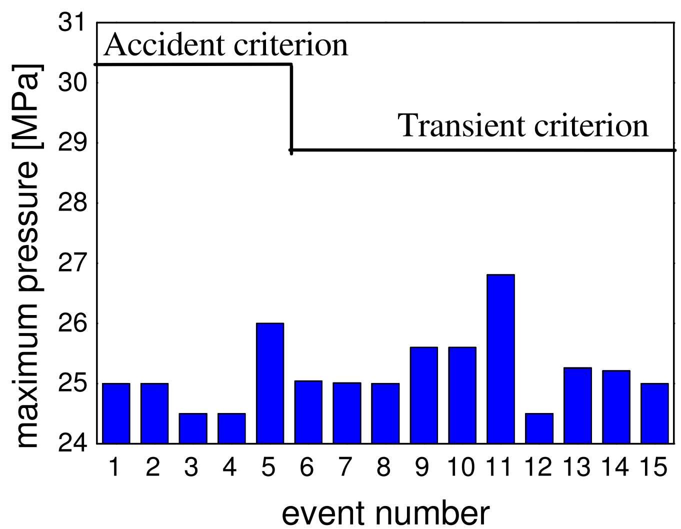
TD- RCIC
AFS

TD-HPCI
AFS

TD-HPCI
AFS

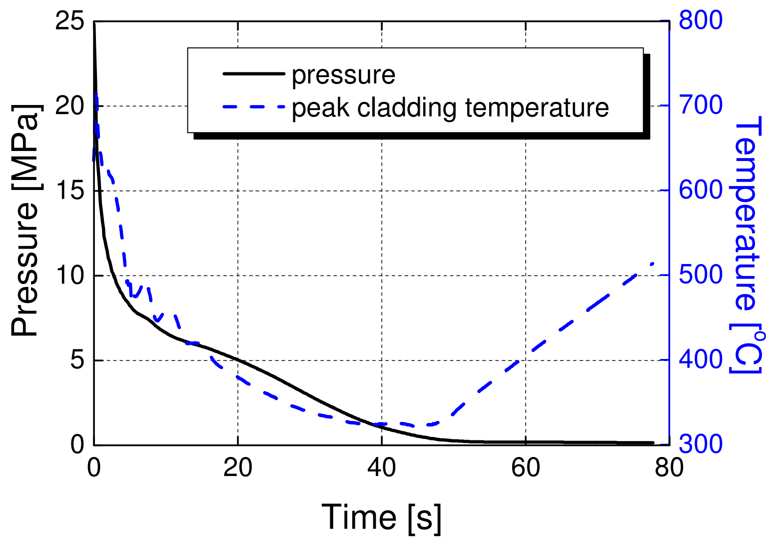
Summary of transient and accident analysis



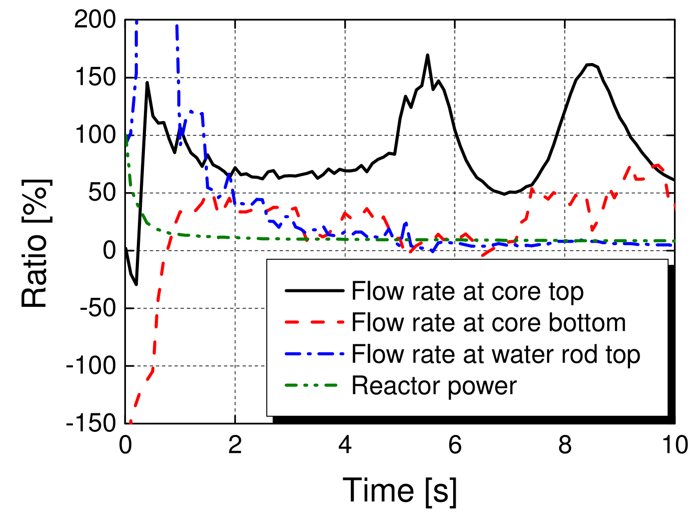


Accidents	
1	**Total loss of feedwater**
2	**Reactor coolant pump seizure**
3	**Control rod ejection at hot standby**
4	**Control rod ejection at cold standby**
5	**Control rod ejection at normal operation**
Transients	
6	**Loss of feedwater heating**
7	**Inadvertent startup of AFS**
8	**Partial loss of feedwater**
9	**Loss of offsite power**
10	**Loss of load with turbine bypass**
11	**Loss of load without turbine bypass**
12	**CR withdrawal at normal operation**
13	**CR withdrawal at hot standby**
14	**Feedwater control system failure**
15	**Pressure control system failure**

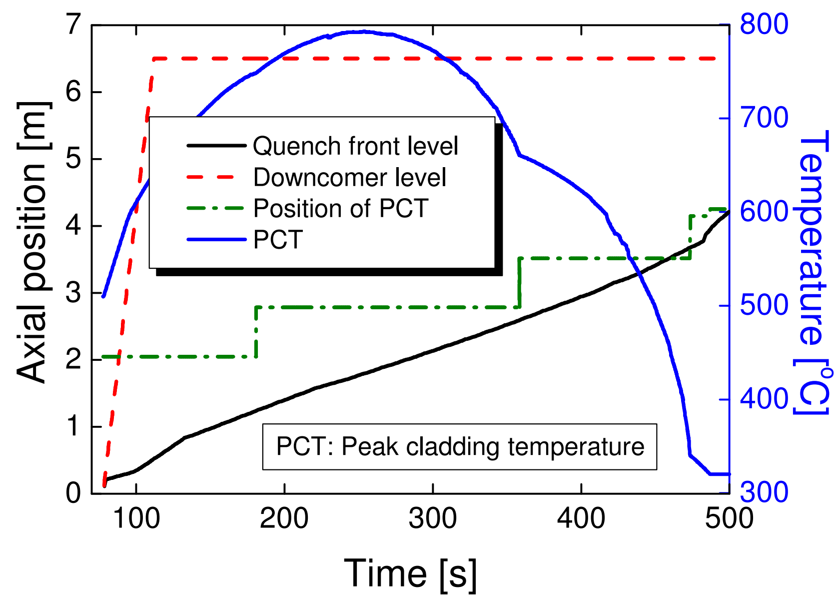
Large LOCA



pressure
peak cladding temperature
Pressure [MPa]
Temperature [°C]
Time [s]

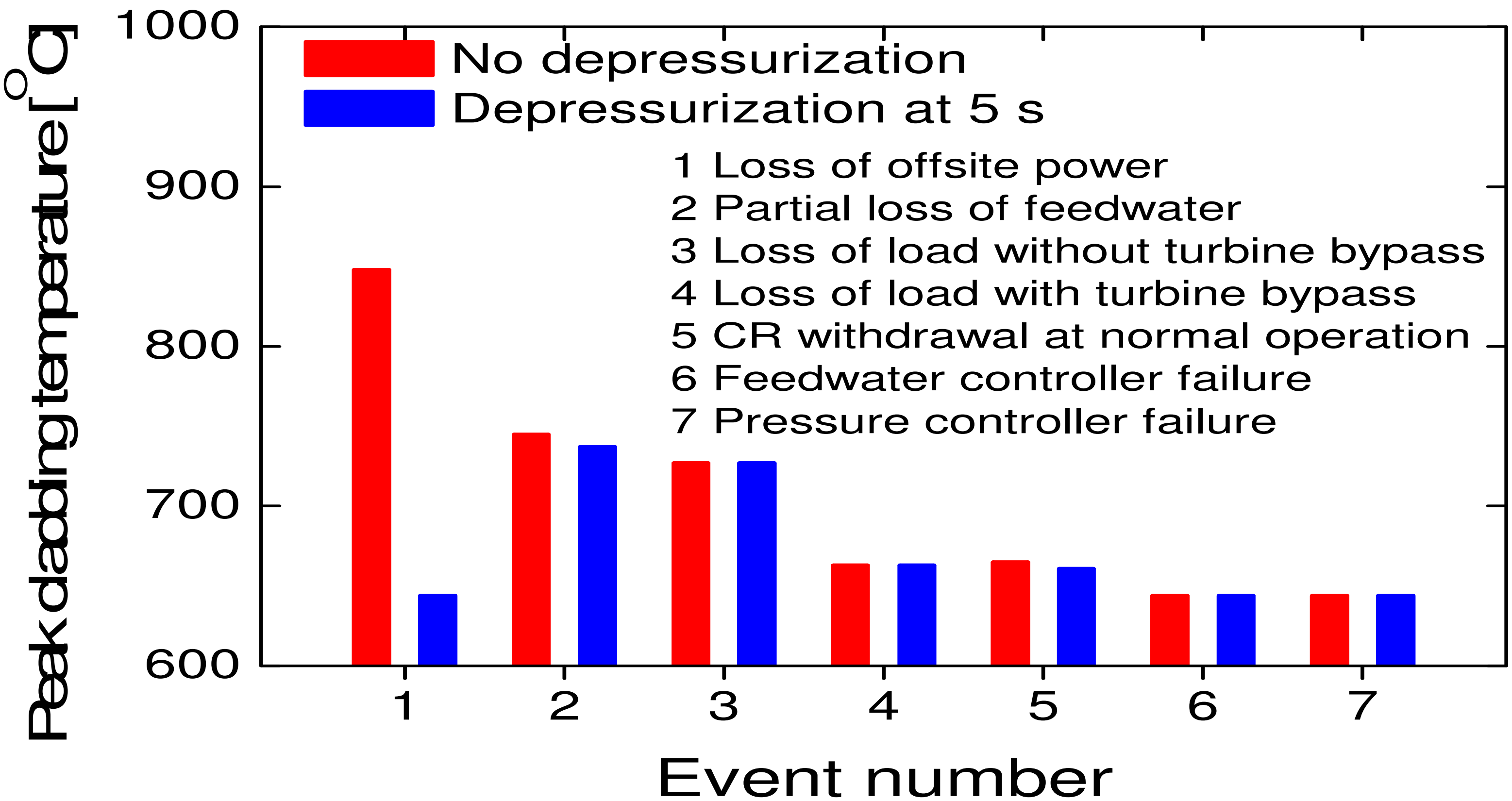


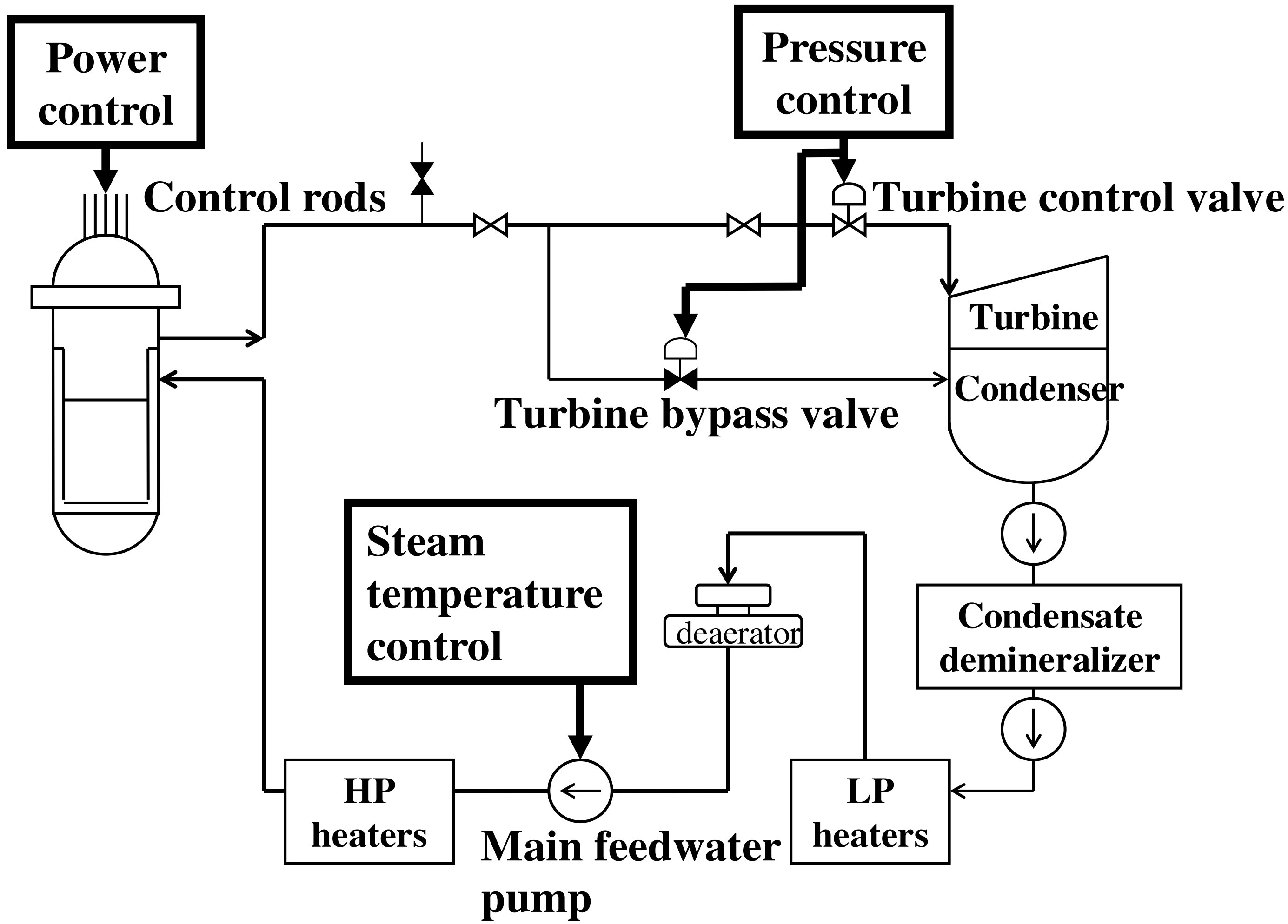
Flow rate at core top
Flow rate at core bottom
Flow rate at water rod top
Reactor power
Ratio [%]
Time [s]



Quench front level
Downcomer level
Position of PCT
PCT
PCT: Peak cladding temperature
Axial position [m]
Temperature [°C]
Time [s]

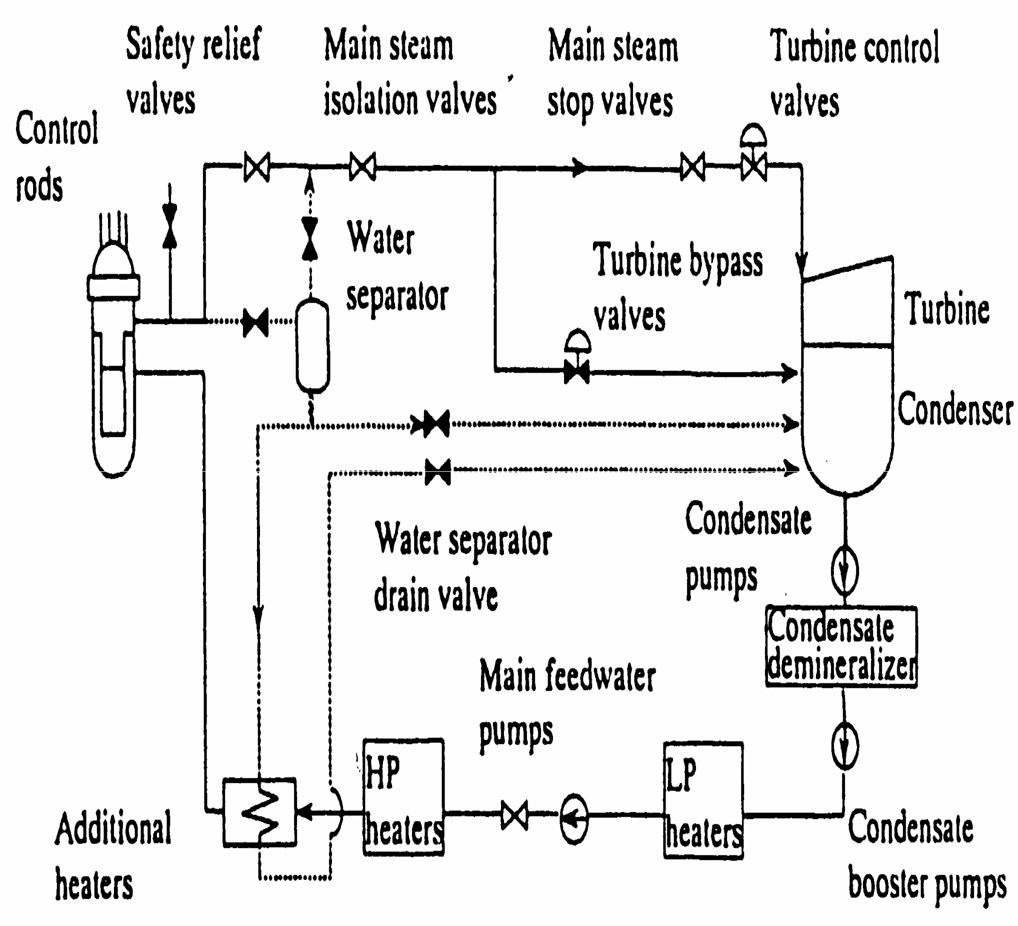
ATWS; no threat of core damage even without depressurization





Control system of SCLWR-H

Sliding Pressure Startup System



Sliding pressure supercritical water-cooled reactor

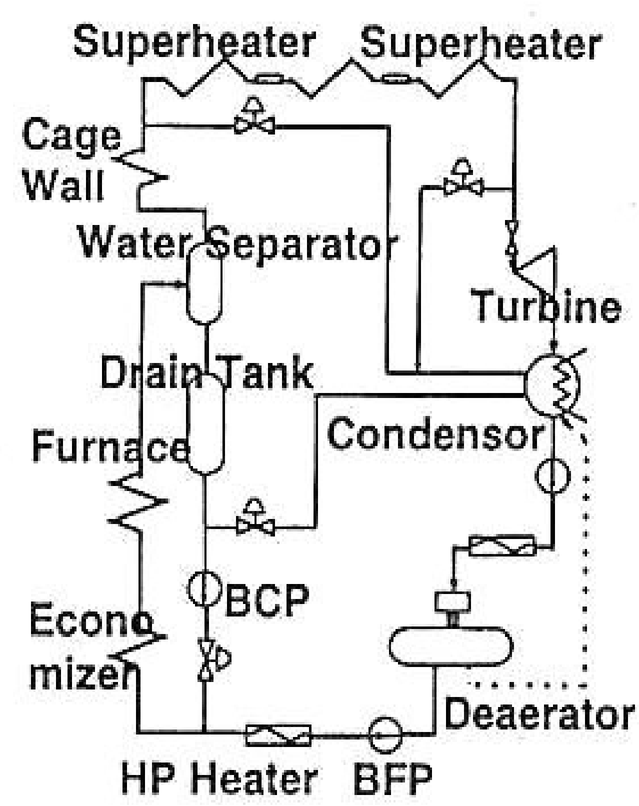


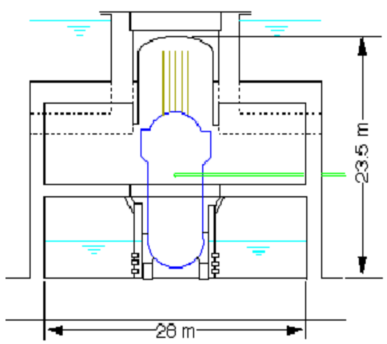
Fig.18 Sliding pressure fossil fired power plant

The reactor starts at a subcritical pressure, which increases with load.

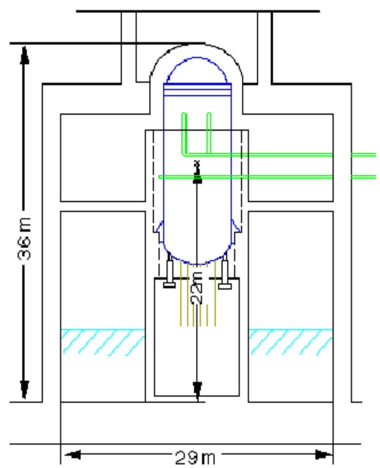
Computer codes and data base

1. Multi-channel coupled neutronics/ thermal-hydraulics
   Water rod thermal hydraulics (SPROD code)
2. Transient and accident analysis
3. LOCA analysis (SCRELA code)
4. Plant heat balance and thermal efficiency
5. Plant control, and start-up
6. Stability
7. Subchannel analysis
8. Data base of heat transfer coefficients of supercritical water

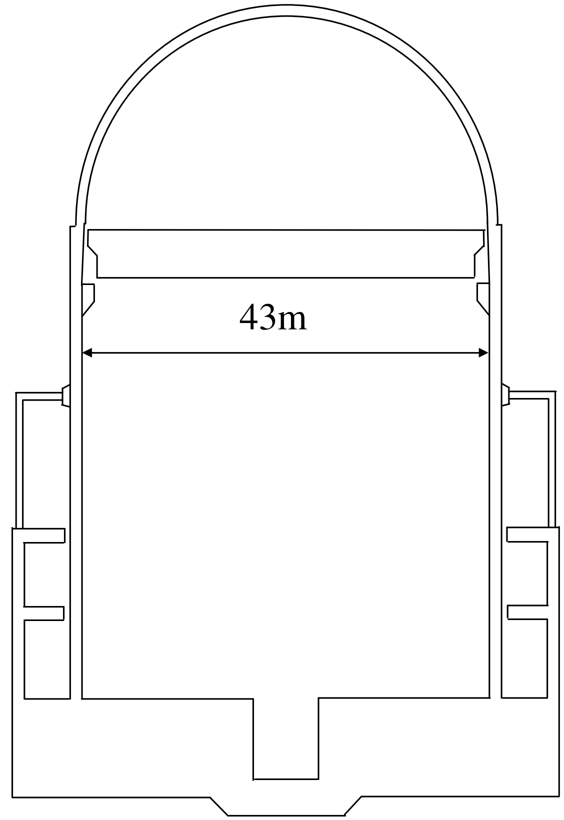
All computer codes were developed except SRAC code of JAERI



SCLWR-H(1700MWe)



ABWR(1350MWe)



PWR(1100MWe)

Comparison of containments

Improvement of 1700MWe SCLWR-H from 1350MWe ABWR

	SCLWR-H	ABWR	improvement in %
Thermal efficiency, %	44.0	34.5	28%
RPV weight, t	750	910	18%
CV volume, m3	7900	17000	54%
Steam line number	2	4	50%
Turbine speed, rpm	3000*	1500*	50%
Condenser	2	3	33%

*3600rpm and 1800rpm in the western Japan

Fast reactor version of SCWR

- Once-through coolant cycle is compatible with tight lattice fast core because of high head pump and low core flow rate. (High pressure drop is not a problem.)
- SCWR becomes a fast reactor with the same plant system. High capital cost problem of fast reactor will be solved.

Status and Collaboration and Related Researches

1989: Started at The University of Tokyo ; Conceptual design

1998: JSPS-Monbusho funding (University of Tokyo) ; Pulse radiolysis and heat transfer

1998: US DOE-NERI funding (ANL); water-chemistry (pulse-radiolysis) experiments

2000: HPLWR program by EC (FZK, CEA, Framatome, VTT, PSI, KFKI and Univ. of Tokyo)

2001:Japanese NERI of METI funding (Toshiba, Hitachi, Univ. of T okyo, Kyushu Univ. Hokkaido Univ.) Thermal hydraulics, materials screening, plant concept

2001:US DOE -NERI funding, 3 programs; Corrosion, thermal hydraulics, design studies

2002: Japanese NERI of MEXT (Univ. of Tokyo, CRIEPI, JAERI, Tosh iba, Hitachi) Water Chemistry

2002: US Generation 4 reactor (only one among water cooled reactor)

Supercritical fossil-fired power plants in USA and Japan

USA developed in 1950's, Largest unit is 1300MWe.

- Philo#6 (125MWe, 31MPa, 621C, 1957)
- Eddystone#1 (325MWe, 34.5MPa, 649C, 1959)

Japan; deployed in 1960 's and constantly improved

- Anegasaki#1 (600MWe, 24.1MPa, 538C, 1967)
- Kashima#5 (1000MWe, 1974)
- Hirono#1 (600MWe, Sliding-pressure, 1980)
- Kawagoe#2 (700MWe, 31.0MPa, 566C, 1991)
- Tachibanawan#1 (1050MWe, 25MPa, 610C, 2001)

28 units (600-1050MWe) started operation in 1990-2000

Goals of R&D

Improving competitiveness of new construction of nuclear power plants in global (de-regulated) market

Advantages

1. No big demonstration reactor is necessary.
   Major components are already demonstrated.
2. Experience in LWR and fossil fuel power plant technologies.
   (within their temperature, pressure and capacities)
3. Single phase flow ; easy to calculate.
4. High temperature ; capability of hydrogen production
5. Compatible with tight lattice fast reactor core

Socio-psychological issues of nuclear power

- “No public death by nuclear reactor accidents in Western countries”. This is a fact and excellent record!
- 100,000 needless additional abortions in Europe after Chernobyl. Fear of Radiation in more dangerous than radiation itself.
- Socio-psychological issues need to be addressed by non-technical means.
- There is another world based on non-technological disciplines.

Risks and Cost-Effectiveness of Selected Regulations

Regulatioı	Year issued	Healtl or safety	Agency	Baselin mortality risl per million	Cost, M$ per prematur death avert(
Unvented Space Heater Ba	1980	S	CPSC	1,890	0.1
Aircraft Cabin Fire Protection Standa	1985	S	FAA	5	0.1
Auto Passive Bestraint/Seatelt Standards	1984	S	NHTSA	6,370	0.1
Underground Construstion Standar	1989	S	OSHA-S	38,700	0.1
Trihalomethane Drinking Water Standaı	1979	H	EPA	420	0.2
Asbestos Baı	1989	H	EPA	NA	110.7
1,2-Dichloropropane Drinking Water Standard	1991	H	EPA	NA	653.0
Hazardous Waste Land Diposal Ban(1st 3ı	1988	H	EPA	2	4,190.4
Municipal Solid Waste Landfill Standards (Proposed)	1988	H	EPA	<1	19,107.0
Hazardous Waste Listing for Wood-preserving Chemicals	1990	H	EPA	<1	5,700,000.0

Source : S.Breyer "Breaking the Vicious Circle" Harvard Univ. Press 1993

Summary

Nuclear energy reduces global warming, enhances energy security and national economy.

Reactor physics; Core discipline of nuclear energy R&D and applications

Let’s work toward “Nuclear Renaissance”